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TRANSIENT DISTURBANCES FOLLOWING GUNSHOT WOUNDS OF THE HEAD.[1]

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DURING the first world war neurologists made so many valuable clinical studies from observation of the wounded that their pupils of the next generation faced with similar cases can often do little but pay homage to the accuracy of work done long ago. It is therefore with some trepidation that I shall attempt to interest you in some of the many transient abnormalities observed in gunshot wounds of the head.

To those who have for long been interested in accidental head injuries, the clinical contrast provided by experience of battle casualties has been most striking. Accidental head trauma from a blunt injury usually leads to instantaneous and widespread arrest of brain activity followed by a slow recovery. Clinical evidence of severe irreversible damage to the brain is usually slight, and focal injury is relatively uncommon. Head wounds from high velocity missiles ("G.S.W.s") which survive to reach a base hospital lead to a very different state of affairs. The effects of local brain damage usually dominate the clinical picture, while the rest of the brain is often so little injured that consciousness is not even temporarily impaired. It becomes possible, therefore, to collect instances of focal injury to most parts of the brain in which there is little hindrance to the investigation of the subjective and objective clinical features which the injury produces. This provides material for many detailed studies, and it is possible in the time at our disposal to touch only superficially on a few of these.

The effects produced by a high velocity missile striking the skull are quite remarkable. There seems to be an explosive effect at the point of contact, and the most remarkable result of this is seen in the shower of bone fragments which often penetrates the brain for several centimetres from the point where a missile glances away from the skull.

[1]Paper read to the Neurological section of the Royal Society of Medicine on April 5, 1945.

In dealing with such a high velocity missile it is not surprising to find that a glancing fragment which hardly damages the skull often injures the underlying brain. That is to say, those cases which are from the surgical point of view G.S.W.s of the scalp only often have an area of cerebral bruising underlying the wound. The clinical evidence of this brain injury is very obvious in scalp wounds over the Rolandic area which cause transient weakness and loss of sensation in a contralateral limb, but the most precise evidence is provided in scalp wounds over the occipital pole, which frequently cause not only transient blindness but may also

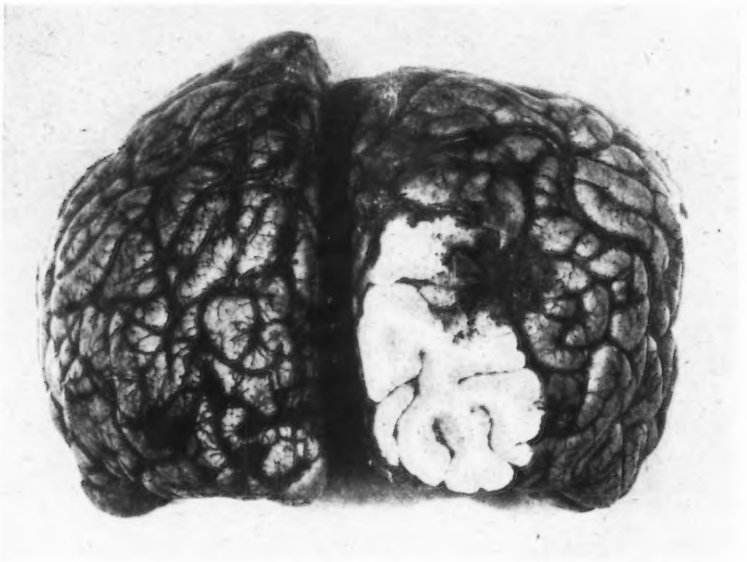

FIG. 1.—Coronal section of the occipital lobe in case of Pte. S.

result in a permanent homonymous scotomatous defect in the visual field.

Further evidence regarding brain damage in these wounds is provided by examination of the cerebrospinal fluid for blood, 100 to 1,000 red blood cells per c.mm. is often counted in the early days after wounding.

The post-mortem appearances are illustrated by the following case:—

Pte. S. (Case 10198) died of a spinal wound (2nd dorsal level) thirteen days after wounding. He also had a mid-occipital wound half an inch in length, and when this was excised the pericranium was found to be torn and the outer table grooved. At post-mortem there was a small crack in the skull under the wound, but no depressed fragments of bone, and the dura mater was quite intact. The underlying brain, however, was severely bruised, as illustrated in fig. 1.

Before leaving this type of case it should be emphasized that, though evidence of brain damage can often be obtained in G.S.W.s of the scalp, there is usually no resulting disability from this type of wound.

Small Superficial Brain Injuries.

Wounds which destroy small areas of brain in the superficial regions of the cerebral hemispheres are of special interest. The immediate effect of these injuries usually indicates that the injured area of cortex is rendered instantaneously inert. There is occasionally evidence of momentary stimulation. For example, a parietal wound may cause a sensation like an electric shock in a limb of the opposite side, or an occipital wound may cause a momentary crude visual hallucination; but generally a parietal wound causes an immediate extinction of local activity, as evidenced by numbness and paralysis, while an occipital wound generally causes transient blindness. A wound in the mid-Rolandic area causes immediate paralysis and numbness of the opposite arm, but in addition to this the affected limb early after wounding shows the features of "spinal shock" —that is to say, there is loss of muscle tone and the tendon reflexes are absent. This cortico-spinal shock, or diaschisis, as von Monakow (1914) termed the phenomenon, has been much studied by physiologists. Under experimental conditions it occurs not only when the spinal cord is divided, but also when the appropriate area of the motor cortex is excised. A modern conception of the shock effect has been formulated by Liddell (1934). He explains that a nerve cell may have hundreds of *boutons* from different sources in contact with it. These *boutons* not only link the neurone with distant organs, but also keep the nerve cell on the *qui vive*, and by their influence reduce the threshold required for an effective stimulus. "The mechanism of excitation is believed to be concerned with the generation of a point of depolarization beneath each *bouton*, so that the threshold for discharge of the cell concerned is influenced (mainly lowered) by the influence of all other cells with which it is in contact."

In G.S.W.s of the Rolandic neighbourhood the features of spinal shock are more marked and much more lasting in the upper than the lower extremity. Thus the tendon reflexes of a paralysed arm often remain absent for many days, while in a similar paralysis of the lower limb complete absence of the knee and ankle jerks are rarely observed even within a few hours of wounding, and usually within twelve hours there is increased tone and exaggeration of knee and ankle jerks. This striking difference in man reflects no doubt the intricacy of the cortical influence over the lower motor neurones serving the muscles of the arm and implies a gross

difference between the degree of cortical control of the upper and lower limb.

Apart from this easily demonstrated cortico-spinal shock, von Monakow's conception of diaschisis included a shock effect to all parts of the central nervous system with which the injured area is in close anatomical connection. Head (1926) after visiting von Monakow defined diaschisis as "a suspension of inactivity falling on those parts where fibres from the site of the lesion terminate in uninjured grey matter of the central nervous system." Von Monakow's remarkable observations are therefore to some extent in accord with the present conception of shock as outlined by Liddell, and it is evident that possible remote or transcortical shock effects of wounds of the brain are worthy of study.

Transient Motor and Sensory Disorders.

As far as the transient symptoms are concerned, the motor and sensory disorders from penetrating wounds of the brain can seldom be separated from each other, as both are usually present. This is so common as to suggest a transient shock effect from sensory to adjacent motor cortex and vice versa.

The motor cortex seems to be specially vulnerable to transient concussive or shock effects—more so than the sensory cortex. Thus, as will be shown later, superficial wounds of the posterior part of the parietal lobe often cause transient paralysis of the opposite arm or leg. It is no doubt to be expected that the transmitting central end of the highly controlled pyramidal tract should be specially vulnerable to shock from the corresponding sector of the sensory cortex. A difference is again noticeable between the behaviour of the arm and leg area of the motor cortex, for in similar shock effects to these areas the lower limb recovers much more quickly, improvement becoming apparent within a day or two, while the upper limb will often remain quite powerless for ten or more days, and then after this long latent interval make a remarkable recovery of the motor functions.

While wounds of the motor cortex generally cause transient sensory loss as well as paralysis, injuries slightly anterior to the pre-central gyrus occasionally result in severe transient paralysis without even temporary subjective or objective sensory disorder.

As one would expect, the nearer the wound is to the Rolandic area the more severe is the transient sensorimotor disorder and the greater the probability of permanent disability. It is of some interest, however, to make a plan of the site of brain wounds which have caused sensorimotor

disorders, either temporary or permanent. In fig. 2 the approximate site of injury in a group of cases which caused both motor and sensory disorder of the opposite lower extremity (L), upper extremity (A), or face (F) are charted, the largely transient (small letters) being separated from the largely permanent (capitals). The approximate depth of the wound in centimetres as estimated by the surgeon or from the radiograph is also shown. The left and right sides of the brain are superimposed. "D" indicates a depressed fracture without dural tear.

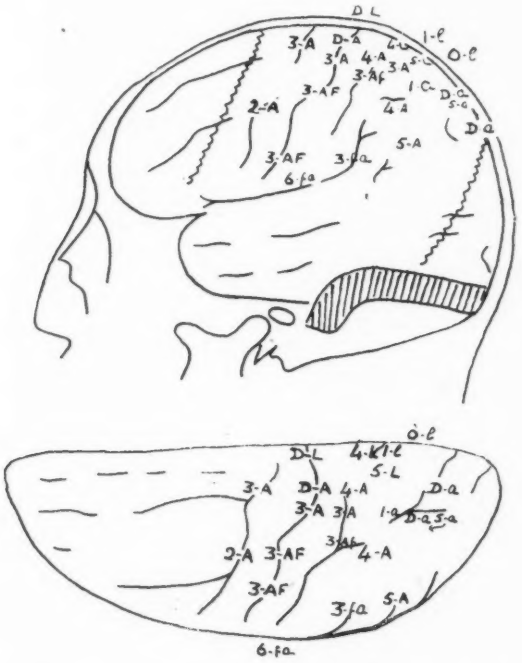

FIG. 2.—To show the position and depth of a series of wounds which caused sensorimotor disturbance in the opposite arm (A) or leg (L). The probable depth of each wound is given in centimetres (see text).

These cases were selected to include only those in which there was little or no disturbance of consciousness after wounding, the post-traumatic amnesia being nil or less than one hour, and were so limited in extent and depth as to affect either the opposite arm *or* the leg, but not both. These criteria aim at excluding cases with deep or remote damage to the brain.

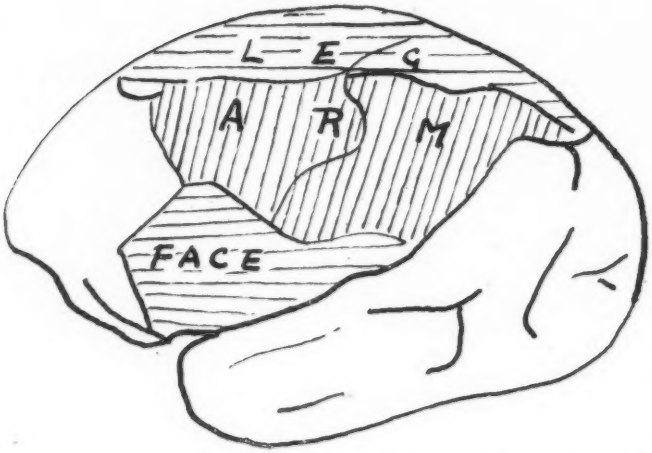

FIG. 3.—The sensory cortex in the chimpanzee (Bailey, Dusser de Barenne *et al.*).

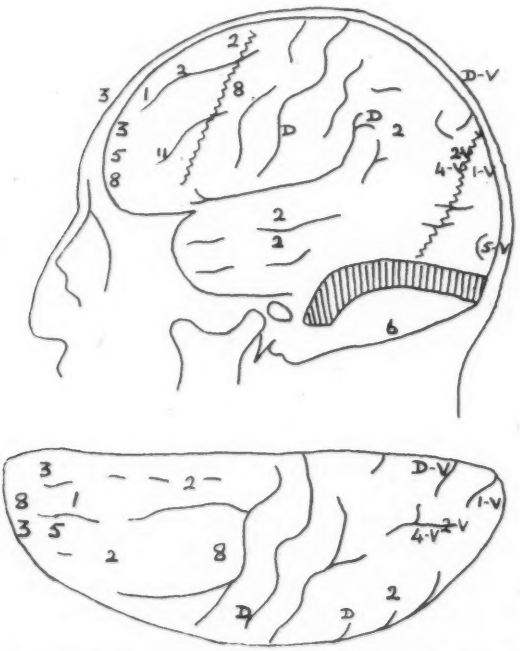

FIG. 4.—The position and depth (centimetres) of a series of wounds which caused no sensorimotor disorder and no disturbance of consciousness.

The charts in fig. 2 probably outline roughly the sensory cortex for the upper and lower extremity in man. They also illustrate the small extent of the leg area on the lateral aspect of the hemisphere. The extent of the face area is not indicated accurately in this study. These wounds caused both sensory and motor disorder in one limb. The transient weakness caused by posterior parietal wounds is of special interest, as has been mentioned, and suggests a trans-cortical shock effect to the motor cortex.

In considering this chart it is of interest to compare it with the extent of the sensory cortex in the chimpanzee as determined by Bailey, Dusser de Barenne, *et al.* (1940) by the local strychninization of the cortex (fig. 3). The posterior limit of the sensory cortex corresponds approximately to that shown in fig. 2, but the pre-Rolandic spread is more extensive. The leg area also appears to be more extensive in the chimpanzee.

Fig. 4 gives the position and depth of some penetrating wounds which caused no subjective or objective sensorimotor disturbances. In none of these cases did the wound disturb consciousness sufficiently to cause even a short period of amnesia. It is obvious from this chart that uncomplicated penetrating wounds of most areas of the frontal, temporal and occipital lobes and cerebellum have little tendency to transmit a shock effect to the motor or sensory function. "V" indicates that the wound affected vision.

Wounds to the posterior parietal and occipital regions sometimes cause transient paralysis and numbness of all four limbs which are clearly due to concussion of the upper cervical cord, and occasionally it is difficult to decide from the patient's story whether transient quadriplegia is spinal or cerebral. In one of these a bilateral hyperæsthetic zone in the neck indicated the level of the cord injury to be at the third cervical segment.

Sensory Disorders.

The disturbances of sensation which result from cortical wounds are worth considering in some detail.

Le Gros Clark (1944) in a recent review writes that in the higher primates the projection of the fillet system through the thalmus to the cortex is practically confined to the post-central gyrus. Dusser de Barenne's (1941) ingenious method of local cortical strychninization has demonstrated in monkey trans-cortical association activity from the pre-central and post-central gyrus to Areas 5 and 7 which occupy a large part of the posteriorly adjacent parietal lobules. The same author and his colleagues (1938) have demonstrated a close reciprocal anatomical and functional connection

between the posterior ventral thalamic nucleus and the post-central cortex. There is no experimental evidence that the cortico-thalamic neurones are inhibitory, as Head suggested; in fact, strychninization of the post-central gyrus leads to an increase in electrical activity of the thalamus. This close reciprocal activity between cortex and thalamus is of special importance in considering wounds of the sensory area. Le Gros Clark (1944) considers that the reciprocal thalamo-cortical connections establish a common functional unit, and that the extensive retrograde cell degeneration in the thalamus which follows cortical disease or ablation finally disposes of any structural basis for Head's conception of the "essential organ" of the thalamus.

A common immediate effect of a superficial penetrating wound of the Rolandic area is to cause paralysis and a feeling of numbness with loss of all form of sensation in the upper or lower limb of the opposite side. The transient loss of touch, pain, and temperature sense is often profound and is associated with the loss of all cortical sensory functions as Head (1918) defined them. The distribution of the cutaneous anæsthesia soon after wounding is remarkable, for when the arm area is involved in any part the whole of the upper extremity to the shoulder often becomes insensitive: but while this often spreads to the upper trunk and face there is relatively little tendency for the anæsthesia to spread to the lower limb. Similarly, when the leg area is injured there is often transient anæsthesia up to the groin which may spread to the lower trunk, but shows little tendency to spread to the arm area. It seems likely in these cases that there is a profound shock effect to the whole cortico-thalamic system for the limb concerned. This common tendency for transient anæsthesia to involve all parts of the one limb is of interest when compared with Dusser de Barenne's experiments in which he found that strychninization of a small focus, say the leg area, "sets the cortex on fire" with large action current spikes which are confined to the whole of the sensory and motor leg area, while the adjacent upper limb area is not affected. Corresponding results were noted with stimulating a small focus of upper limb sensory cortex. As the effect of strychnine fails to spread from the upper to the lower limb area (or vice versa), so in wounds of the cortex the shock effect, though spreading to inactivate the entire sensory system for the upper limb, often shows a striking disinclination to spread its effects to the leg area of the cortex.

Deep pressure pain usually recovers quickly after Rolandic wounds, a strong stimulus causing a highly unpleasant sensation referred to a large area of the affected limb. This is illustrated by the following case.

Case of severe injury to the lower Rolandic area to illustrate the early recovery of some primitive sensory functions.

Pte. O. (Case 10268) was wounded by a shell fragment on October 23, 1944. He remembers being injured, but has a post-traumatic amnesia for a few minutes. The wound was over the Rolandic fissure 9 cm. from the sagittal sinus. Operative debridement by Major Small on the day after the wounding left a cavity in the brain the size of a plum. After the injury he felt as though he had lost his left arm, which was numb and completely paralysed. He was, however, able to move the left lower limb to some extent.

Six days after wounding there was still complete flaccid paralysis of the left upper limb, with absent reflexes. The left lower limb retained about 50 per cent. of normal strength at the hip and knee. There was gross raising of the threshold for pin-prick and touch on the left half of the body, especially for the upper limb, but over-reaction to adequate painful stimulus. The radiation of strong pin-prick or muscle pinch was striking: thus, stimulating the left hand led to a highly unpleasant sensation in the left side of the chest in the mammary region, while from the left foot an unpleasant cold, tingling sensation spread up the leg and thigh to the lower abdomen on the left. Strong pin-prick to the chest at the mammary level, especially near the mid-line, was referred to the right side of the chest at the same level. There was complete loss of position sense and ability to localize pain in the left upper and lower extremity and the left ear.

A week later, on November 6, paralysis of the left upper limb was still quite complete. The lower limb was still weak. The sensory state, however, had altered. The threshold for pain, heat and cold was still much raised, but the radiation of a painful stimulus was much less extensive, and localization of pain was crudely correct to the segment of the limb stimulated. Postural loss remained gross.

A month after wounding the left upper limb had recovered 30 per cent. of the strength of all muscle groups—but individual finger movements were impossible: muscle tone was reduced, but the reflexes were slightly increased. The muscles were soft and thin. Impairment of pin-prick persisted, but to a less degree. Postural sense and stereognosis remained grossly impaired in the upper extremity and to a less degree in the lower limb. This case will not be followed further at present.

Recovery of cutaneous sensibility following Rolandic wounds follows slowly and is often incomplete, leaving areas of analgesia or hypalgesia which may be permanent and may take a variety of shapes. One of the commonest is segmental in type and may, for example, involve the inner two digits and the ulnar side of the forearm, or may involve the thumb and index fingers with the radial side of the forearm and the face. Hypalgesia with a peripheral distribution is also common and is often mistaken for an hysterical disorder. These many anatomical varieties of cutaneous sensory loss to touch, pain and temperature following cortical wounds were studied by French and German neurologists during the Great War (Kleist, 1922; Foerster, 1936). Those parts of the limb which have permanent cutaneous hypalgesia usually have loss of postural sensibility and of stereognosis in the segments affected. For example, when there is perma-

nent cutaneous hypalgesia of the fourth and fifth fingers there will usually also be loss of position sense and 2-point discrimination in these digits, while sensation in the other fingers is relatively normal. This correspondence between the fingers permanently involved both in cortical sensory loss, as defined by Head, and in loss to pain, touch and temperature makes it difficult to accept Head's view that cortical injuries can permanently do little to alter the threshold for primary forms of cutaneous sensibility. The analgesia often affects such a small segmental or peripheral area of the limb that the causative lesion can only be at or near the cortex.

We must beware lest our clinical views regarding the functions of the sensory cortex be to some extent confused by confining our observations to cases with superficial lesions of the post-central gyrus and parietal lobules. From the anatomical point of view, the main flow of fibres from the posterior ventral nucleus of the thalamus is to the posterior wall of the central sulcus. This is Area 3 of Brodmann and it barely emerges from the sulcus to reach the lateral aspect of the post-central gyrus. The adjacent Areas 1 and 2 also receive part of the sensory projection, but these are narrow bands which, together with Area 3, form the area post-centralis. Adrian's (1941) studies have confirmed this anatomical view. By electrical recording of the arrival of sensory impulses at the cortex he has found that the somatic sensory cortex in monkeys is confined to the *area post-centralis* of Brodmann. He also found that stimulation of tactile receptors is handed on to the cortex by the thalamus without much alteration. The posterior wall of the central sulcus is over 2·5 cm. in depth, so that the major part of *area post-centralis* lies deeply buried below the surface of the brain in the central sulcus.

In order, therefore, to study the effects of injury to *area post-centralis* we must in the first place select wounds which penetrate the region of the central sulcus for a depth of about 3 cm. It is obvious that more superficial wounds and those which penetrate the posterior part of the post-central gyrus will damage only an insignificant area of primary sensory cortex.

In the study of localized penetrating wounds of the brain near the Rolandic fissure the early profound loss of all forms of sensation in the opposite upper or lower limb has already been referred to. In the first days and weeks which follow such injuries the early widespread anæsthesia shrinks, and localized areas with loss of all forms of sensation of a segmental or peripheral type are often observed. The loss of pain, temperature, touch and vibration sense usually recovers, while some loss of postural

sense and of stereognosis remains. In a proportion of the cases, however, a profound impairment of all forms of sensation persists, becoming a permanent disability. I have found that this is most liable to occur in localized wounds which are so situated that a part of the *area post-centralis* is probably severely injured. Thus, fig. 5 gives the approximate position and depth of the wound in cases in which there has been persistent impairment of all forms of sensation in a part of the opposite upper or lower extremity.

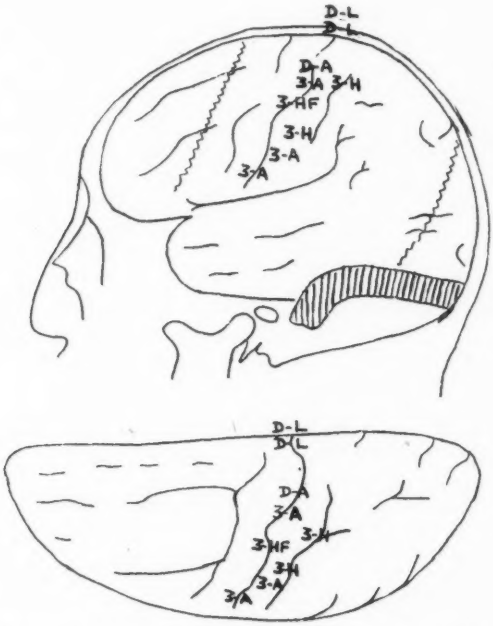

FIG. 5.—The approximate position and depth of some wounds which caused permanent impairment of all forms of sensation in one contralateral limb.

The position of the sensory loss in these cases confirms its cortical site. Thus, if in fig. 5 we take the upper five of the wounds affecting the arm from above downwards, all forms of sensation were impaired as follows: (1) ulnar half of hand and fingers; (2) all fingers; (3) all fingers; (4) upper lip, thumb, index and middle fingers; (5) thumb and index finger, with impairment of 2-point discrimination in the upper lip.

It should be emphasized that these cases are selected to include small wounds which lead to sensorimotor disorder in either the upper or lower

extremity, but not both. Fig. 5 indicates clearly that in these local wounds causing loss of all forms of sensation the site of injury was very close to the Rolandic fissure and of such a depth that severe injury to a part of the primary sensory cortex in the posterior wall of the central sulcus is likely.

Fig. 6 gives the position and depth of some similar small wounds which have permanently impaired the discriminative sensory functions only. It is apparent that in this group with clear dissociation between the

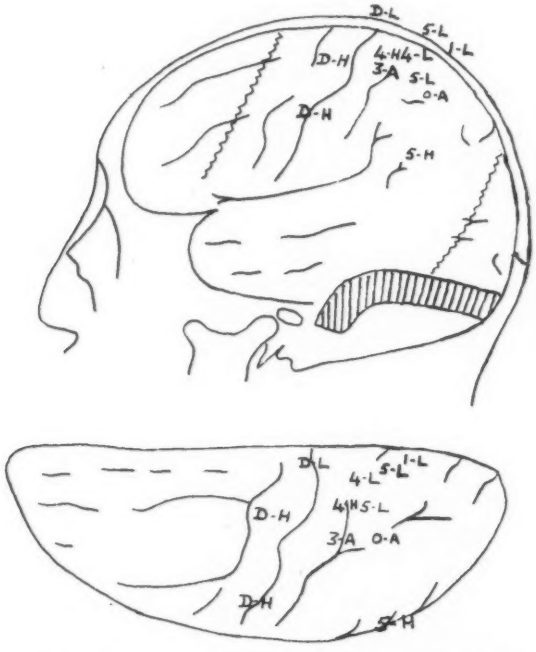

FIG. 6.—Position and depth of some penetrating wounds which caused permanent impairment in one limb of discriminative sensory functions only.

primary forms of cutaneous sensibility and higher sensory discriminative functions, the wounds tend to be placed more posteriorly or are more superficial than those in fig. 5 and are thus less likely to injure severely the posterior wall of the central sulcus.

These two groups of case are illustrated by the following:—

Post-Rolandic wound causing transient paralysis and loss of all forms of sensation in one arm, but permanent loss of discriminative sensory functions only.

C.Q.M.S. S. (Case 10649) was wounded on December 24, 1944. His wounds included one of the left parietal region, a laceration of the base of the right thumb, and compound fracture of the tip of the right index finger. The wounds were accompanied by no disturbance of consciousness. He at once thought he had lost his right arm, and when he saw it was still there he assumed he had been badly wounded at the shoulder. There was no dysphasia. He walked 50 yards to the R.A.P. The wounds of his paralysed (right) hand caused him no pain for two or three days after wounding, even when dressed and debrided with a pair of scissors. At No. 3 Canadian C.C.S., a few hours after wounding, he was reported as having paralysis and numbness of the right hand, and sensation was impaired on the radial half of the hand and forearm. Operation on the brain injury was carried out by Major Keith two days after wounding, bone chips being removed to a depth of 2 cm.

The paralysis and sensory loss in the right arm improved quickly, and by the time he reached this country eight days after wounding, pain and vibration sense were normal in all the fingers, while touch was only slightly impaired. Position sense was grossly defective in all the fingers and wrist, but normal at the elbow and shoulder.

On January 29, 1945, five weeks after wounding, the right forearm muscles were soft and hypotonic and measured 3 cm. less than on the left. He is right handed. There was good motor power at elbow and shoulder, but the strength of crude movements of wrist and fingers was only 20 to 30 per cent. of normal. The thumb could be moved separately, but individual movements of 3rd, 4th and 5th digits were impossible. The arm reflexes were much increased in the affected (right) upper limb.

Touch, pin-prick, heat, cold and vibration sense were unaffected and equally felt on both hands. Localization of point of touch was accurate to the correct phalanx and correct digit in all fingers. Two-point discrimination was largely correct at 1 cm. on the thumb, but failed even at 5 cm. on digits 3, 4 and 5. Appreciation of passive movement required about 20 deg. for correct response in thumb, about 30 deg. at wrist, while he failed at maximum range of over 90 deg. in digits 3, 4 and 5.

When examined on March 29, 1945, there was little change in the above findings.

This, therefore, was a case in which after the initial shock effect had passed there was quick recovery of the primary sensory functions and persistent loss of the discriminative, sharply confined to the right hand and wrist. The wound in this case was very close to the central sulcus, the site of the brain penetration being 1 to 1½ cm. behind the central sulcus. This is near to the primary sensory cortex already mentioned, and this type of case makes one hesitate to maintain that all superficial wounds destroying the full depth of a section of the central sulcus cause the permanent local loss of pain, touch and temperature to which I have referred, though the cases of strictly local wounds which show this pheno-

menon have all been at or very near the central sulcus. The following is a typical example:—

Rolandic wound causing permanent gross impairment of all forms of sensation in one hand. Early phantom limb.

Tpr. F. (Case 9689) was wounded by a fragment of shell on August 19, 1944. There was no disturbance of consciousness, but an immediate sensation of numbness of the whole of the left upper limb, left face, tongue, and alveolar margins. The left arm was useless and the left face "dragged." There was no subjective numbness of the trunk or lower limb, and he walked without limping to the R.A.P. He was seen within twelve hours of wounding by No. 6 Mobile Neurosurgical Unit, where paralysis was complete only in the left hand, which was also analgesic. There was a parietal wound, approximately over the Rolandic fissure 6 cm. from the mid-line, with bone fragments penetrating the brain for about 3 cm. It so happened that the same shell wounded the paralysed hand, shattering the second phalanx of the left middle finger. This wound at first gave him no pain, and the first dressing an hour after injury was quite painless. A second dressing applied two hours after wounding caused a sharp, shooting pain which was referred to a phantom left upper limb which he felt was above his head. He also found that when he pulled the paralysed left arm across his chest this caused a similar sharp pain in the phantom above his head. As position sense slowly recovered in the limb the phantom became smaller and disappeared. The remaining disability four and a half months after wounding consisted of weakness largely confined to the fingers of the left hand. Pin-prick, heat, cold and touch were grossly impaired in the fingers and to a lesser degree over the hand and forearm, especially on the radial side of the limb. Position sense was now good at shoulder, elbow and wrist, but still very grossly defective in all the fingers, where the direction of even the maximum range of movement could not be recognized. Stereognosis was lost.

This case illustrates the features of Rolandic wounds as already described. In addition, the occurrence of a phantom suggests that a high level of the sensory system concerned with spatial discrimination was intact, but isolated. It is clear from the position of the wound that the parietal lobe posterior to the post-central sulcus may well have escaped damage. This case, therefore, provides evidence suggesting that the discriminative sensory functions of the parietal lobules depend on the integrity of *area post-centralis* and not on a separate projection from the ventrolateral nucleus of the thalamus.

The type of sensory loss in this case would, I think, have been described by Head as sub-cortical, as there is a precise raising of the threshold for all forms of sensation. The term sub-cortical, however, has little anatomical meaning, as there is no relay between the thalamus and sensory cortex, and it seems that so-called sub-cortical sensory loss is really due to a wound which reaches the depth of the primary sensory cortex in the posterior wall of the central sulcus. Small missile fragments which under-

cut a section of the Rolandic area have a similar effect, as indeed Head described.

Penetrating wound by a small fragment of shell which undercut the motor and sensory leg area of the cortex.

Gdsmn. F. (Case 9360) was wounded on August 3, 1944. A small fragment of shell penetrated the right frontal region above the frontal sinus just to the right of the mid-line. Radiological examination showed this fragment in the upper posterior parietal lobe, 1½ cm. to the right of the mid-line. While it is generally dangerous to assume that the track of the missile can be calculated by the position of the metal fragment, the clinical picture suggests in this case that the course of the missile could be inferred with a fair degree of confidence.

The wound caused no disturbance of consciousness, but the left leg was immediately paralysed and the left arm weak. He was examined within seven hours of wounding by Lieutenant-Colonel McArdle, who found complete paralysis of the left leg and loss of position sense in the left foot and left hand with astereognosis. There was over-reaction to pin-prick of all the left side of the body, but the threshold was probably raised. Light touch was not felt over the left foot and was diminished over all the left side. Four and a half months after wounding there was flaccid paralysis to voluntary movement of the left leg below the knee which was almost complete. The knee and ankle jerks were increased on the left, with an extensor plantar response. The muscles of the left calf were soft and thin, the calf measurement being 2 cm. less than on the right. There was considerable impairment of all forms of sensation below the knee, as tested by pin-prick, hot and cold, touch, appreciation of passive movement, 2-point discrimination, localization of point of touch and vibration sense. All forms of sensation seemed equally affected with a definite threshold.

The clinical features of the sensory loss in this case were, therefore, very similar to those penetrating the Rolandic area and are again of the type Head described as sub-cortical. The highly localized sensory loss must be due to injury near the cortex, and there seems no reason to justify a distinction between this type of injury and that which destroys the full depth of the primary sensory cortex by a penetrating wound of the central sulcus.

Those cases, therefore, whose wounds are represented in fig. 5 had persistent and pronounced disturbances of all forms of sensation in a part of the affected limb. The wounds were all so situated and of such a nature that destruction of a sector of *area post-centralis* down to the depths of the central sulcus is quite probable. The effects of destroying a segment of the *area post-centralis* have not, I think, been sufficiently studied, though Kleist (1922), from his studies of war wounds, held the view that Area 3 was specially concerned with pain and temperature sense. Peele (1944) in recent ablation experiments in monkeys reported impaired response to pin-prick after removal of Areas 3, 1 and 2. The absence of infection in small penetrating wounds of the brain treated by modern methods provide

for study many discrete lesions of the cortex which should be fully made use of for research purposes.

The subject presents many difficulties. The appreciation of a painful stimulus, for example, may depend on the establishment of a neuronal circuit—possibly from thalamus to *area post-centralis* and back to the thalamus. Such a mechanism would be rendered temporarily functionless in wounds involving *area post-centralis*, but the partial recovery of the primary sensory functions which often occurs would suggest that there are alternative pain circuits which can be established. Further, areas of permanent cortical analgesia in the upper extremity are almost always most marked in the hand, that part of the body which has the most extensive cortical representation. This observation indicates that this hypothetical pain circuit is more dependent on the cortex in the case of the hand than for other parts of the body.

The chief difficulty, however, in interpreting the effects of these small wounds of the sensory cortex lies in the fact that in gross wounds of the same area which destroy most of both the motor and sensory cortex the patient usually recovers good cutaneous sensibility in the affected limbs. In these cases gross hemiplegia and loss of the discriminative sensory functions persist while appreciation, pain, temperature and vibration recover well. *We thus come to the apparently paradoxical finding that while limited wounds of the Rolandic area often cause permanent loss of all forms of sensation in a contralateral limb, gross injuries to the same area permanently destroy discriminative sensory functions only. The further study of these surprising observations cannot be pursued at present.*

Hyperpathia, Hyperæsthesia and Paræsthesia.

One result of wounds of the sensory cortex of great interest is the occurrence of perverted sensation. Foester (1936) refers to "hyperpathia" occurring in early stages of recovery from wounds of the post-central gyrus. This term refers to a pain sense that, though the threshold is raised, has an explosive character, is of great intensity, long duration and wide radiation, that its features are similar to those which occur in injury to peripheral nerves, spinal cord, fillet and thalamus. Indeed, these cases may show the over-reaction to pain which Head and Holmes (1911) and Riddoch (1938) describe as characteristic of the so-called thalamic syndrome.

The following case illustrates the phenomenon:—

L/Cpl. C. (Case 9139) was wounded on July 16, 1944. A fragment of mortar bomb grazed the right upper parietal region, lacerating the scalp for 7 cm. and

injuring the pericranium in the anterior part of the wound, but there was no evidence either at operation or by radiography of any injury to the skull. He remembered the wound, but had a subsequent amnesia for about fifteen minutes. He was examined at No. 6 Mobile Neuro-surgical Unit within a few hours of wounding, where he was found to have some weakness of the left foot, but the striking abnormality, confirmed in this country two days later, was hyperpathia. Any touch of the left lower limb up to the level of the groin evoked a gross over-reaction—an electric shock sensation. Contact of the left foot with the ground or a light touch to the limb caused a sensation of pins and needles over the whole extremity up to the groin. The threshold for pin-prick was slightly raised. Examination was difficult owing to the discomfort caused by handling the limb. There was marked loss of postural sense and two-point discrimination of the affected limb. Localization of points of touch was impaired, but not to a gross degree. The hyperpathia ceased gradually in about ten days, as sensation recovered, and the residual disability in the leg was very slight.

The hyperpathia of cortical wounds is not, in my experience, associated with severe spontaneous pain such as may occur in damage to the sensory system at or below the thalamic level. Paræsthesiæ—tingling or pins and needles—are often referred to contralateral limbs, but there is no severe spontaneous pain. In the thalamic syndrome hyperpathia and spontaneous pain seem, according to Head and Holmes (1911), to be variations of the same disorder. In cortical wounds the same may probably be said of hyperpathia and paræsthesiæ. As in the thalamic syndrome, the excessive reaction to pain or touch may be associated with little or no hypalgesia. Indeed, one is sometimes justified in using the term hyperæsthesia for these cases.

Symonds (1931) has emphasized the essential similarity between the sensory over-reaction in injuries to the peripheral nerves, posterior nerve roots, spinal cord, brain stem and thalamus. From experience of superficial wounds of the cerebrum, it seems that the sensory cortex may be added to this list.

In ten cases with cortical hyperpathia, motor weakness and loss of the discriminative sensory functions (position and stereognosis) have, in the acute stage, been constant and pronounced features in that part of the body to which the sensory disorder was referred. Some persistent disturbance of the discriminative sensory functions (often slight) was demonstrated in all cases examined two or three months after wounding, and in a few there was persistent impairment of pain and touch. Some weakness persisted in most of the cases (seven of the ten). The site of wounding in some of these cases is given in fig. 7.

This cortical hyperpathia may, therefore, follow injury to many areas of the sensory cortex. It may occur when all discriminative sensory functions are abolished, but while the threshold for pain, touch, heat and

cold is little altered. Should one make the assumption that hyperpathia depends on damage to the pathway for pain, then its occurrence in superficial cortical wounds emphasizes the importance of the sensory cortex for the appreciation of the painful stimulus. This assumption is not, however, justifiable on the evidence provided by these cases. Grant *et al.* (1944) have recently shown that a damaged part of a peripheral nerve acts as a synapse whereby efferent impulses may travel up injured afferent nerve fibres. The observations are of great interest, and should a similar

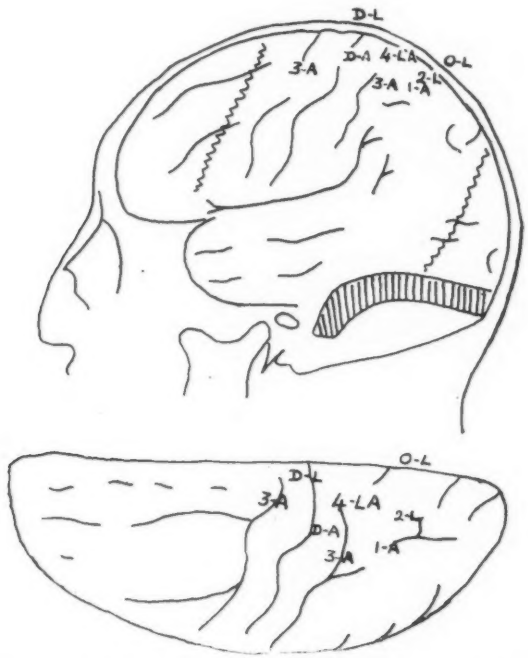

FIG. 7.—Position and depth of some wounds which caused hyperpathia.

mechanism occur in the central nervous system we would be provided with a useful explanation of some central sensory disorders.

In conclusion, I regret that there are many aspects of our subject which are omitted from this paper, while some of the observations recorded are to some extent provisional and require more detailed study. The study of sensory and other disturbances following wounds of the brain are so beset with problems that further co-ordination between the clinician and

the experimental anatomist and physiologist would be advantageous for their further elucidation.

I am indebted to so many for help and advice with this paper that it would be tedious to mention names. I would, however, like to thank especially the Medical Officers at a Military Hospital for Head Injuries and those attached to Mobile Neurosurgical Units, whose careful clinical recording, under trying conditions, has been a constant source of inspiration. I am also indebted to Lieutenant-Colonel L. S. C. Roche, *M.C.*, for permission to refer to cases in the hospital under his command.

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A STUDY OF PUPILLARY INEQUALITIES IN MAN.

BY ERIC A. TURNER.

THIS paper describes a simple clinical test for investigating the cause of inequalities of the pupils: the test consisting of application of eyedrops of cocaine and adrenaline to both eyes simultaneously. A technique is described which will give equal dilatation in the two eyes in normal subjects, and the interpretations of variations from this normal are discussed.

Inequalities of the pupils may present problems difficult to solve by clinical methods alone. Even observation of the reactions to light and the pupillary movements associated with accommodation and convergence may not supply much fresh information for the diagnosis, and other positive neurological signs may be lacking It has long been suggested that special tests should be employed to elucidate the problem in such a case. In 1938 the *Société de Neurologie de Paris* held a discussion on the question of pupillary functions, in the course of which it was pointed out in reviews of the position by Bollack and Monbrun that observation of the pupils might be either accurate only within rough practical limits or completely accurate within the limits of error of the instrument used for observation and measurement.

(*a*) Most accurate of the strictly scientific methods was the cinematograph method which Löwenstein and Westphal (1933) described. By employing light at the violet end of the spectrum, these observers were able to photograph the pupil in what was, as regards pupillary reaction, comparative darkness. By adding measurable amounts of ordinary light the whole range of pupillary reactions could be photographed and later measured. Accurate graphs of the reaction could be prepared in dimensions including both extent of contraction and time of contraction, and thus slight degrees of third nerve paresis could be differentiated from slight degrees of sympathetic disturbance. This method had proved highly satisfactory and could be freed from the usual fallacies which attend pupillary measurements. (Since 1937 Löwenstein and Friedman have been employing infra-red rays in similar studies.)

The disadvantage of this method was that the apparatus involved, and the care with which the experimental conditions had to be chosen, meant that the tests could not be applied under ordinary clinical conditions.

(*b*) Clinical methods begin with observation of the two pupils by un-

aided vision, their site (exactly central or otherwise), their shape, their approximate size and their equality and otherwise. It was noted that the normal pupils were usually central, regular, and equal, but might be eccentric, the displacement being towards the nasal or inferior aspect of the iris by as much as one-sixth of the pupillary diameter. Usually circular, the pupils might normally be symmetrically oval. The view was taken that in the normal person, looking straight ahead under normal conditions of lighting, the pupils were equal. Inequality which was observable clinically under such conditions was considered to be abnormal, although the cause of such abnormality might not be clear. Simple direct observation was quite sufficient to note any significant degree of inequality. For the size of the pupils, the simple types of pupillometer gave some help but could not compare in accuracy with the more precise studies of Löwenstein and Westphal. In normal subjects, when the gaze was turned laterally, the pupil of the eye of the side to which the gaze had been diverted was slightly dilated compared with the other side (Tournay's sign).

The iris was considered worthy of study. Signs of inflammation past or present, depigmentation or atrophy, gave valuable information in determining the cause of a pupillary abnormality. Atrophy associated with a Horner's syndrome suggested a lesion of congenital or "obstetrical" origin.

The dynamic changes occasioned by alterations of lighting or by eye movements could be observed clinically, but accurate recording was difficult without recourse to the cinematographic method described above.

The final method of clinical investigation was that of eye-drops (collyria). By stimulating or paralysing either the sympathetic or the parasympathetic supply to the pupils and observing the response, additional information could be gained, and this method was considered to be one worth further development for clinical purposes, especially in view of the advances in our knowledge of the sympathetic and parasympathetic systems.

It is reasonable to suppose that if collyria could be found which would give equal changes in the two eyes of normal persons, useful information could be obtained. For example, if a technique could be found which would cause maximal and equal stimulation of the sympathetic innervation of the pupils, resulting in equal dilatation in normal pupils on the two sides, two simple clinical tests (that of collyria and that of direct comparison of the two pupils) could thus be combined to provide a result easy to achieve and observe, accurate for practical clinical purposes, and valuable in the information it provided.

This paper is the result of a search for such a test. Three main types of case were studied:

(*a*) A series of 50 normals was examined to test the validity of the method used.

(*b*) 37 post-traumatic cases of various types were examined by the method of collyria.

(*c*) 11 cases showing spinal lesions were examined as being potential sympathetic lesions.

In addition, 18 miscellaneous cases were examined, consisting of tumours, intracranial aneurysms, subdural hæmatomata, &c.

Anatomy and Physiology.

The pupil is controlled by two opposing muscle groups each with its appropriate nerve supply. The central control of the sympathetic system in the hypothalamus is transmitted to the pupil by a long and circuitous route. Descending through the tegmentum of the mid-brain to the antero-lateral columns of the cervical cord, the pathway emerges at the level of the first and second thoracic segments, reaches the first thoracic ganglion and proceeds up through the inferior and middle cervical ganglia to synapses in the superior cervical ganglion, lying roughly opposite the second cervical vertebra. From there it passes to the plexus on the internal carotid artery, whence it emerges to lie in close proximity to the trigeminal ganglion and ultimately joins the naso-ciliary branch of the ophthalmic division of the fifth cranial nerve. The sympathetic fibres leave this nerve as the long ciliary nerves which enter the eye near the optic nerve, penetrating the sclera and supplying the sclera, the ciliary body and the dilator pupillæ. Sympathetic fibres also pass directly to the nerve of the levator palpebræ superioris. The two nerve supplies to the latter muscle are synergic, and paralysis of either can cause ptosis, though the forms of ptosis are not identical.

The parasympathetic supply to the pupil passes from the nucleus of the third nerve, probably in the bilateral Edinger-Westphal nuclei or the medial nucleus ventral to these. Where the third nerve divides into superior and inferior divisions, the pupillary fibres go with the inferior, proceeding out along the branch to the inferior oblique muscle. From this nerve they emerge as the short parasympathetic root to the ciliary ganglion, which lies just lateral to the optic nerve and ophthalmic artery. The short ciliary nerves carry the fibres from the ganglion through the sclera to reach the ciliary body and the iris. Other roots of the ciliary

ganglion are a small sympathetic branch and a ramus communicans from the naso-ciliary nerve.

While the sympathetic and parasympathetic fibres lie in adjacent nerves in the superior orbital foramen, the parasympathetic fibres are closer to the musculo-tendinous ring. While the sympathetic supply has a longer extracranial course the parasympathetic supply has a longer and more vulnerable intracranial course.

Pharmacology.

With certain modifications, sympathetico- and parasympathetico-mimetic drugs have the actions that might be expected of them when applied directly to the conjunctival sac and allowed to diffuse through the cornea to reach the muscles controlling the pupil. Thus pilocarpine and physostigmine cause the pupil to contract, cocaine and atropine cause it to dilate. Adrenaline applied in this way has little effect on the normal pupil, producing a small dilatation only after repeated applications and after thirty minutes' delay (Magitot, 1938). Ephedrine does act, causing mydriasis. Novocain does not dilate the pupil, but when associated with adrenaline has a certain mydriatic action. Acetylcholine produces no effect on the pupil with simple instillation. Suggested paralysants of the sympathetic system such as ergot derivatives have given variable results.

Pilocarpine is believed to act directly on the parasympathetic receptors, and produces contraction of the pupil in an enucleated eye. Physostigmine is believed to inhibit the destruction of acetylcholine by enzyme action at the parasympathetic nerve endings. Atropine paralyses the parasympathetic supply; the mode of action is not clear. The mode of action of cocaine calls for some discussion. Earlier doubts concerning its actions have been in part cleared up. Both on the pupil and on blood-vessels its action is to potentiate adrenaline. This it is believed to do by attaching itself to the enzyme which destroys adrenaline in the body, and also by attaching itself to the sympathetic receptors themselves. Cocaine and adrenaline are thus synergic. Ephedrine, like adrenaline, acts directly on sympathetic receptors.

Pathology.

The only pathological condition in which the actions of the above collyria have been much studied is that of sympathetic palsy—as in Horner's syndrome. In old-standing cases of this some form of degeneration occurs in the nerves as far as the iris, and some change occurs even in the sympathetic receptors themselves. Thus Tinel reports that after ablation of the stellate ganglion in man, once degeneration has occurred,

adrenaline produces an appreciable dilatation of the pupil (this is also a well-known finding in animal experiments). Magitot, after Byrne, suggests that abnormal sensitivity to adrenaline circulating in the blood explains the "paradoxical dilatation" which sometimes occurs naturally in cases of Horner's syndrome. After sympathetic section, neither cocaine nor ephedrine produces as much dilatation on that side as on the normal side. Löwenstein and Friedman (1942) suggest that lesions in the cord cause either a sympathetic stimulation or a Horner's syndrome which responds to cocaine but not to adrenaline. Lesions in the "second neurone" between the cord and the superior cervical ganglion produce, according to them, a Horner's syndrome which responds neither to cocaine nor to adrenaline: while lesions peripheral to the superior ganglion leave a pupil which responds to adrenaline but not cocaine. It should be noted that these views are not confirmed by the observations of Tinel: from the present series it appears that sympathetic irritation can occur at a more peripheral level than the cord, while Horner's syndromes from lesions at all levels give a reduced response to a mixture of cocaine and adrenaline on the affected side. It is noteworthy that if cocaine is injected intravenously in such an instance it produces a greater dilatation on the affected side.

Although there is not evidence on the scale of that available for adrenaline, there is reason to believe that a comparable sensitivity comes into play once parasympathetic fibres have degenerated (Wright, 1940).

The Tests.

Coppez has been given the credit of first suggesting in 1903 that collyria could be used in the elucidation of pupillary inequalities.

Danis and Coppez (1926) in studying cases with unequal pupils put cocaine first into the larger pupil. They concluded that:

(i) If there were no further dilatation, the condition must be due to sympathetic stimulation.

(ii) A good dilatation means that there was paralysis of the sphincter.

(iii) Feeble dilatation means a normal pupil.

They then put cocaine into the smaller pupil, and decided that feeble or absent dilatation means a spasmodic myosis. Atropine would then produce a large dilatation. Conversely paralytic myosis would be shown by a feeble dilatation with atropine.

These interpretations are not beyond argument, and in any event the tests may be easy to interpret in gross cases, but when abnormal signs are slight, accurate observation is difficult. Clearly a simpler test is called for,

and preferably one capable of allowing comparison between the two pupils at each stage. A search has therefore been carried out for such a test. Firstly pupillary change has to be brought about in a way capable of interpretation, e.g. by stimulating one system (the sympathetic or the parasympathetic) and thus putting an additional "pull", as it were, on the sphincter or the dilator pupillæ respectively. Secondly, a test has been sought which will produce equal and synchronous dilatation on the two sides in normal subjects.

Certain of the collyria may be rejected forthwith on theoretical or practical grounds. Physostigmine acts only via such acetylcholine as is present, so would not be expected alone to give any information capable of interpretation, except in complete third nerve palsy (either a sympathetic or a parasympathetic inequality would be liable to persist after physostigmine). Atropine produces such a wide dilatation that small inequalities tend to be masked. It does not reveal a parasympathetic disturbance and is not capable of making more evident a sympathetic inequality, as it relaxes the dilator, not putting it on the stretch. In practice, it and its homologues have not been found to give satisfactory results.

Theoretically pilocarpine should suffice in order to test sympathetic weakness of one side, or degeneration of the parasympathetic nerve receptors. In practice it was found to have serious defects when used in 1 per cent. solution in the same way as is described below for the other tests. It did not satisfy the second criterion, for it was not found possible to secure constant results in normal subjects, about half of whom showed small but definite inequalities in some of the readings. A few results in abnormal cases have been studied, but interpretation of these must be guarded as the myosis in both eyes is so marked that differences between the two sides are never striking.

4 per cent. cocaine solution, used alone, would depend upon both the sympathetic production of adrenaline and the tone of the sphincter muscle, and interpretation of the results would be impossible. In practice it has been found that even in normal eyes cocaine, like pilocarpine, gives unequal results. In the case of cocaine it seems likely that this is due to very small differences in the natural production of adrenaline in the two eyes, which become exaggerated by the dilating effect of the cocaine. Normally they are masked by the strong action of the sphincter pupillæ. 4 per cent. ephedrine hydrochloride solution stimulates the sympathetic system and causes a marked dilatation of the pupil. With suitable technique, it might be possible to produce a maximal peripheral stimulation, leading to equal dilatation on the two sides in normal eyes. Such a dilatation would be

capable of interpretation. Ephedrine must therefore be considered as theoretically adequate as a testing collyrium. It has only one disadvantage. It causes smarting of the eyes and a fairly profuse lacrimation. This effect does not diminish with repeated application, so that no matter how many drops are inserted, it is never certain that a significant quantity is not washed out. Avoidance of these side-effects would entail careful experimentation with solutions of varying osmotic tension and pH.

In an attempt to stimulate the sympathetic dilators, the mixture of cocaine and adrenaline is justified on theoretical grounds. By these two collyria, a maximum stimulation is achieved of the dilator pupillæ, independently of the local production of adrenaline which may be disturbed by transient lesion of the sympathetic supply, and provided only that true degeneration of the sympathetic receptors has not occurred.

Before considering the respective merits of ephedrine and the cocaine-adrenaline mixtures, we may consider the action of ephedrine in the various possible abnormalities which can occur in the control of the pupil.

(*a*) Third nerve palsy: (i) from transient block: (ii) accompanied by degeneration.

Ephedrine could not be expected to differentiate between these two. In both it would increase the difference between the two pupils in a regular fashion, by putting an increased strain on the sphincter.

(*b*) Third nerve stimulation. Here ephedrine would not be expected to increase the difference, but to diminish it or leave it unchanged. It would probably not abolish it.

(*c*) Sympathetic palsy: (i) from transient block. Here ephedrine will abolish the pupillary difference. (ii) From a long-standing condition accompanied by degeneration. Here ephedrine increases the pupillary difference, the smaller pupil being the abnormal one and responding much less than a normal eye to drops.

(*d*) Sympathetic stimulation. In this case ephedrine should abolish the pupillary difference.

On purely theoretical grounds it would be expected that the cocaine-adrenaline mixture would act in exactly the same fashion as ephedrine. However, collyria do not always act as they are expected to (cf. adrenaline, acetylcholine), and it must be remembered that certain cases of old-standing Horner's syndrome are reported as becoming sensitive to adrenaline. With this reservation the two collyria would seem to have equal merit. The deciding factor has been the local anæsthetic action of cocaine. The first drop causes almost as much smarting as ephedrine, but subsequent drops fall on an anæsthetized cornea and are comparatively painless.

Lacrimation is accordingly greatly reduced, and it has proved easier to secure an equal dilatation in two eyes in normals. As it turns out, dilatation in old-standing Horner's syndromes has been greatly reduced with the cocaine-adrenaline mixture, so that in all respects these drops act for ordinary clinical observations exactly as ephedrine as outlined above, with the added advantage of local anæsthesia.

The Technique.

A solution of 4 per cent. cocaine in 1:1,000 adrenaline is used. The pupils are first observed in moderate, uniform lighting, such as diffuse daylight, the eyes focused on a distant object and looking ahead (for lateral deviation of the eyes produces inequality). The reactions to light and on accommodation are observed, then one drop from an ordinary eye-dropper is put in each eye. The patient experiences smarting in the eyes for a few seconds, and lacrimation results. The flow of tears ceases after about half a minute, after which another drop is put into each eye. This time, smarting is minimal and momentary, but in a further half-minute a third drop is inserted. This time the solution feels "like water," and no more need be added in most cases. Occasionally, however, lacrimation is so profuse that the solution is largely washed away and the third drop still causes smarting. A fourth drop is then necessary.

Readings are taken every fifteen minutes, being noted at the time, like the preliminary observations, on a piece of paper. This seemingly trivial point is important if preconceived notions of the case are not to interfere with the results and their interpretation. Only after the whole series of observations has been made should the observer try to make his interpretation. Readings can be recorded as R = L, R > L, or R < L, or an approximate drawing of the pupil can be made, actual size and shape, to provide a record of the degree of dilatation and the presence of irregularity. The latter method has been adopted in most of the cases in this series, but for convenience the recordings in this paper are by the first method, with the addition of certain initials.

Thus, s = slightly; + = difference increased; w = wide dilatation, e = eccentric; i = irregular.

The observations are limited to five readings, covering one hour, during which clinical examinations of the cases can be performed, or in the case of routine observations 6 to 10 cases can be observed in the time. It is found that the dilatation is usually passing off in the last reading, and an inequality at that time seems to be of no significance. Similarly readings taken within fifteen minutes of the application of the drops have been unreliable. Maximum dilatation occurs at either the third (thirty minutes) reading, or at the fourth (forty-five minutes) reading. These are the most reliable single readings, but the whole series has to be read to convey the maximum significance.

It was observed that when the test was repeated within the next few days on the same patient, the cocaine and adrenaline mixture had less effect than the first time. This fatigue phenomenon persisted long after the active dilatation, which indeed passed off in a few hours. The precise duration of the fatigue cannot be determined without accurate pupillometry, but it seemed to pass off in about a week. It had no detrimental effect on subsequent pilocarpine tests, which could be performed next day without any greater fallacy than usual. Although the dilatation with cocaine and adrenaline was less when repeated during the period

of fatigue, the results were not at variance with the first results. When a difference between two pupils had been accentuated by the drops, as in third nerve palsies, it was noted that this accentuation seemed to persist to a small degree for about three days after the obvious dilatation had gone.

Results.

A. Normals.

Fifty normal controls were examined, subjects giving no history or symptomatology of nervous disease. Of these, 5 showed slight inequality in some of the readings during the first forty-five minutes and could therefore be taken as significantly abnormal. 3 of the 5 showed very slight inequality in the preliminary observation. These numbers correspond with the 5-10 per cent. of symptomless "normal" subjects who are known to show inequality, especially when the pupils are dilated by fear, excitement, &c. The normal subjects with pupillary inequality showed also irregularity of the smaller pupil which was considered to be greater than average, and it is suggested that in most cases these represented slight abnormalities of the sympathetic supply, of long standing and with slight "degeneration" of some sympathetic fibres. The long extracranial course of these fibres and the frequency of cervical adenitis from all causes, lung disease (Berner, 1942) and of birth injuries were taken as arguments in favour of this possibility. Cases presenting with an otherwise symptomless inequality appeared in two groups, those with constant inequality fell into the class of a true Horner's syndrome, while others with a variable inequality showed either a slight inequality with irregularity after dilatation (? a minimal sympathetic "degeneration" as above), or an equal dilatation. The last type of cases was thought to represent a partial "transient block" of the sympathetic pathway of unknown cause.

In summary, then, there is evidence that the test satisfies the first of the two criteria mentioned earlier, viz. that of producing equal dilatation on the two sides in normal people.

B. Abnormals.

Full tabular results were prepared of 66 abnormal cases, but in the interest of brevity these have been summarized under headings below.

1.—Acute Head Injuries Presenting With Inequality.

Sixteen cases in this category were examined. Usually these were tested within forty-eight hours of the injury. In severe cases the "acute" period was taken to extend up to two months, after which the injury was classed as "old."

Twelve of the cases showed dilatation on both sides, with the difference between the two sides accentuated especially in the second and third read-

ings after the collyria of adrenaline and cocaine solution. These cases were taken to be examples of third nerve palsy in the eye with the larger pupil, and Case 2 is reproduced as a sample.

Case No.	*Clinical diagnosis*	*Results of tests*	*Comment on results*
2	Recent head injury with inequality	R < L	Partial left third nerve palsy
		R < L+	
		R < L+	
		R < L	
		R < L	

Some cases were repeated later and showed progressive improvement. After the resting inequality had disappeared, it could still be brought out by the test. Case 1 illustrates this.

Case No.	*Clinical diagnosis*	*Results of tests*	*Comment on results*
1 (*a*)	Recent head injury with inequality	Rs > L	Partial right third nerve palsy
		R > L	
		R > L	
		Rs > L	
		Rs > L	
1 (*b*)	Same case, one week later. Inequality now gone	R = L	Tests inconclusive in themselves, but consistent with earlier result above
		R = L	
		Rs > L	
		R > L	
		Rs > L	

The pupillary inequality did not always appear immediately after trauma. In Case 8 it appeared about the fourth to fifth day and was always slight. Nevertheless testing with collyria produced a typical result.

Case No.	*Clinical diagnosis*	*Results of tests*	*Comment on results*
8 (*a*)	Recent head injury. Hæmatoma round right eye. Tests done on second day (within twenty-four hours of injury)	R = L	No evidence of nerve lesion
		Rs > L	
		R = L	
		R = L	
		R = L	
8 (*b*)	Same case of mild head injury two weeks later	Rs < L	Results point to a partial left third nerve palsy
		R < L	
		R < L	
		R < L	
		R < L	
8 (*c*)	Same case, six weeks after injury	R = L	Tests inconclusive in themselves, but consistent with diagnosis suggested in 8 (*b*)
		R = L	
		Rs < L	
		Rs < L	
		R = L	

It will be noticed that the hæmatoma here was round the opposite eye. This was true of 4 of the cases in which the site of the local lesion was in or near one orbit. In 4 others in which the site was also known, the presumed third nerve lesion was on the same side as the obvious external trauma. The only possible fallacy here is an irritative third lesion of the eye with the smaller pupil. This does not seem likely as it would be

expected to be transient, and in some cases at least to go through to a stage of palsy (as has been suggested in severe basal lesions). No clear case of reversal has been seen in these milder types. In any case a third nerve palsy has not been diagnosed unless the difference has been accentuated and not merely persistent.

Diplopia was present in only 5 of the 12 cases. Wherever the cause of the diplopia was discovered the diagnosis arrived at by collyria was found to be consistent with the known nerve lesion.

Case No.	*Clinical diagnosis*	*Results of tests*	*Comment on results*
7 (*a*)	Recent head injury with inequality. Left frontal fracture. Diplopia (left inferior oblique palsy)	R < L R < L R < L + R < L R < L	Partial left third nerve palsy
(*b*)	Same case, a month later. Very slight diplopia persisting	R < L. R < L R < L Rs < L R? < L	Probably still some palsy

Most of the injuries were frontal or temporal, but in several there was no external evidence of the site of the blow.

In addition to these 12 cases, 4 cases were examined which showed no evidence of third nerve palsy on the collyria test. One was a parietal depressed fracture, one a gunshot wound of left temple: a third was a left temporal injury with transient right hemiparesis and a "lazy" left eye: and the fourth was a trivial head injury with dilatation of both pupils (presumably from excitement and fatigue, which were both present at the time of examination). It was taken that these cases presented an initial inequality due to sympathetic disturbances or else to third nerve irritation. Where the side of the lesion was known, it was on that of the larger pupil in 2 cases (the 2 temporal injuries) and on the side of the smaller in one case (the parietal fracture). It would seem possible that the former cases were due to sympathetic disturbance, the latter to third nerve irritation (*see* Cases 9 and 6).

Case No.	*Clinical diagnosis*	*Results of tests*	*Comment on results*
6	Recent head injury, with inequality. Left parietal depressed fracture. Vision of L. eye poor since accident. No field defect	R > L R = L R > L Rs > L Rs > L	Tests inconclusive of third nerve palsy. ? third nerve irritation
9	Gunshot wound, left temple, two months previously	Rs < L R = L R = L R = L R = L	No evidence of third nerve lesion. ? sympathetic disturbance

The site of the lesion in the parasympathetic system is open to considerable discussion. It might seem to be peripheral from the frequency of frontal local damage, but the occurrence of contralateral mydriasis is noticeable. He recalled Karplus and Kreidl's production of mydriasis by electrical stimulation of the frontal cortex (1910).

Two of the cases in this series of 12 were known to have gross damage to the frontal lobes, which is a common site of brain laceration in closed head injuries.

Other views are those of McCreery and Berry (1928), who considered that the mydriasis is due to direct inhibition of the fibres of the third nerve itself. Jentzer (1935) considers it is a phenomenon of irritation of the sympathetic centre in the hypothalamus.

The results of this series would not seem to bear out the first and last suggestions. Peripherally the condition appears to be one of weakness of the sphincter, whatever the origin of the diminished activity of the parasympathetic system.

Many authors have stressed the fact that the third nerve is susceptible to pressure from above and laterally, as pointed out by Woodhall and others (1941). Macewen (1893), Cushing and others have demonstrated herniation of the hippocampus causing pressure on the third nerve in cases of abscess and tumour. Jefferson (1938) has discussed and illustrated the resulting "tentorial pressure cone" in tumours.

In traumatic cases M'Kenzie (1938) suggests four possible causes of the pupillary inequality.

(1) Hæmorrhage in the brain-stem.
(2) Avulsion of the nerve, or pressure of it against the posterior cerebral arteries.
(3) Traction from the brain-stem being pushed to the other side.
(4) Hippocampal herniation.

There is, however, little direct proof in uncomplicated head injuries of the *milder* type that any of these factors is present to such a degree as to cause marked signs. It may be that there the third nerve disturbance is even more peripheral.

One variety of case is not represented in this present series, namely, the severe basal lesion, presenting the cycle of pupil changes emphasized by Cairns—those of myosis followed by mydriasis firstly on the more affected side, either from subdural hæmatoma or severe basal contusion. These cases must be observed carefully without interference by collyria in an experimental stage, as operation may be necessary. Tests by collyria would have to form a separate study.

It has been suggested that the myosis here is from parasympathetic irritation, but the possibility of sympathetic palsy must not be forgotten, especially in view of the other basal changes which seem probable in the opinion of Jefferson (1944). The mydriasis will be due to one of the factors mentioned above as suggested by M'Kenzie.

II.—Recent Head Injuries Presenting Originally With Inequality, but Tested After the Inequality had Disappeared.

Three such cases were examined. Two had been trivial injuries, and showed no definite abnormality to collyria test. In one the previous pupillary abnormality reappeared, suggesting third nerve paresis.

Case No.	*Clinical diagnosis*	*Results of tests*	*Comment on results*
19	Right middle meningeal hæmorrhage treated six weeks previously. At first R > L.	R = L R > L R > L R > L R > L	Tests suggest right third nerve paresis

This case had been transferred from another hospital where the original note on the inequality of the pupils had been made.

III.—Recent Head Injuries Without Inequality.

Four such cases were tested.

In two of these, pupillary inequality developed suggesting evidence of third nerve palsy. Three are of interest in themselves, and are reproduced.

Case No.	*Clinical diagnosis*	*Results of tests*	*Comments on results*
20	Fractured base of skull, with left otorrhœa, and complication of leptomeningitis. Injury recent, pupils to superficial examination equal	R? > L R < L R < L R = L R = L	Strongly suggestive of a left third nerve paresis
21	Fracture of right malar. Right eye less prominent than left (? mechanical)	R = L R = L Rs < L Rs > L R = L	Tests inconclusive of true nerve damage—support displacement diagnosis
23	Recent severe head injury. No focal damage except R VI	R = L R = L R = L R = L R = L	No evidence of third nerve lesion

IV.—Old Head Injuries With Inequality of the Pupils.

In these cases of old head injury the tests were made two to six months after injury.

Ten cases were examined, and 4 showed evidence of third nerve palsy to the collyria test. Where the side of the lesion was known (3 cases) it was on that of the larger pupil. All 3 had frontal injuries and 1 an occipital (contralateral) in addition. The fourth had no external clue to the side of the injury.

Of the remaining 6 cases, 3 showed on testing with collyria a wide dilatation with complete disappearance of the inequality. These were taken to indicate a sympathetic disturbance. They comprised 2 minor head injuries, 1 with a fractured spine in addition, and 1 penetrating occipital wound.

The other 3 cases were inconclusive.

V.—Old Head Injuries Without Inequality of the Pupils.

Four cases were seen. In 3 the pupils dilated equally giving no evidence of any nerve damage, all readings being equal.

In one inequality suggested third nerve involvement.

Case No.	*Clinical diagnosis*	*Results of tests*	*Comment on results*
35	Moderate head injury. Injury near left eye. Diplopia upper left at first	R = L R < L R < L R < L R < L	Tests strongly suggest left third nerve lesion

VI.—Cases of Cervical or Spinal Lesions Capable of Involving the Sympathetic Pathway.

Eleven cases were examined. Of these 4 could be diagnosed clinically as cases of unilateral Horner's syndrome, and all showed results of testing consistent with a sympathetic degeneration on that side. That is, the affected pupil dilated little if at all and became irregular in outline. The picture in gross cases was quite different from the result seen in cases of third nerve palsy. In the slighter degrees the pupil might appear only eccentric, rather than palpably irregular. Two cases are given as examples.

Case No.	*Clinical diagnosis*	*Results of tests*	*Comment on results*
54 (*a*)	Mild "neuritic" pain down left arm. Grossly diminished sweating left side of face. Left pupil more active than right	R < L. R > Le R > Le R > L	Suggestive of a left peripheral sympathetic "degeneration"
54 (*b*)	Same case, tested with pilocarpine	R < L. R = L R = L R = L R = L	No evidence from this test of sympathetic lesion

Case No.	*Clinical diagnosis*	*Results of tests*	*Comment on results*
55 (*a*)	Left Horner's syndrome following abscess left side of neck about level of thyroid cartilage, eighteen months previously	R > L. R > Li R > Li R > Li R > L.	Left peripheral sympathetic "degeneration"
55 (*b*)	Same case, tested with pilocarpine	R > L. Rs > L. R = L. R = L. R = L.	No evidence from this test of any sympathetic lesion

Three further cases showed results of a similar nature on testing, but the side of the lesion could not be determined with certainty from clinical examination. One case was of fracture dislocation at C5-6 with both arms spastic: and one was a bilateral brachial neuritis. One (Case 62) was followed up, and the interesting fact emerged that this phenomenon had disappeared a month later. It is possible that it does not entail a true degeneration but only a transient block of sufficiently long standing.

Case No.	*Clinical diagnosis*	*Results of tests*	*Comment on results*
62 (*a*)	Laminectomy for prolapsed intervertebral disk, C4-5. One month after transient quadriplegia on getting up. Now in plaster collar	R = L R > Li R > Li Rs > Li R > L	Sympathetic peripheral "degeneration" on left side
62 (*b*)	Same case, three days later	R = L Rs < L. Rs < L R = L. R = L.	Effect of drops less after this short interval, but still consistent with above
62 (*c*)	Same case, a month later. Free of symptoms during that time	Rs < L. R = L. Rs < L. Rs < L. R = L.	Results probably of no significance. ? irritation now of left sympathetic

Four cases of cervical lesions, a tumour, a dislocation at C4-5, a soft tissue injury and a case showing root pains were examined and showed no evidence of involvement of nerves controlling the pupils.

VII.—Miscellaneous Cases.

Eighteen miscellaneous cases were examined of such diverse nature that summary is impossible. One or two small groups only emerge, of which the most interesting is the group of intercranial aneurysm.

Four cases of intracranial aneurysm on the internal carotid artery—and of these one had a third nerve palsy—were confirmed by collyria. The other 3 cases were all consistent with a peripheral sympathetic degeneration. Only one case was doubtful clinically. One is given as example.

Case No.	*Clinical diagnosis*	*Results of tests*	*Comment on results*
41 (*a*)	Left intracavernous aneurysm, ten months after first symptom of paræsthesia in eye. Four months after onset of diplopia (VI) and pain in eye	R? < L. wRs > L. wRs > Lw R = Lw R = L.	Original difference in size possibly due to slight third nerve weakness. Tests not really conclusive, but suggest peripheral sympathetic "degeneration" on left side
41 (*b*)	Same case, tested with pilocarpine	R? < L. Rs < L. Rs < L. Rs < L. Rs < L.	? peripheral third nerve "degeneration"
41 (*c*)	Same case, two weeks later following an exacerbation with complete then partial ptosis. Only VI diplopia at times of examination	R < L. Rs < L. Rs > Li R > Li R > Li	Evidence of left peripheral sympathetic "degeneration." Ptosis cleared up half an hour after the drops were inserted
41 (*d*)	Same case, tested with pilocarpine	R < L. R < Li Rs < L. Rs < L. Rs < L.	Any third lesion on left side can only be peripheral

A case of subarachnoid hæmorrhage was seen one month after the acute episode. It showed equivocal evidence of a peripheral sympathetic lesion.

One case of meningioma was examined before and after operation (Case 46).

The most likely explanation here is that a right third nerve weakness became converted by operative trauma into a predominantly sympathetic weakness.

It is known that in a combined lesion the sympathetic element appears predominantly, as in Case 41 above.

Case No.	*Clinical diagnosis*	*Results of tests*	*Comment on results*
46 (*a*)	Meningioma growing from under surface of right tentorium. Before operation	R L. R L. R L. R L. R L.	Right third nerve palsy, or left sympathetic "degeneration"
46 (*b*)	Same case, six weeks after operation. Still in bed, and vomiting	R < L. R < L. R < L. R < L. R < L.	Left third nerve lesion predominant, or right sympathetic "degeneration". Probably operative trauma
46 (*c*)	Same case next day, tested with pilocarpine	R < L. Rs < L. Rs < L. R < L. Rs < L.	Tests inconclusive, but consistent with right sympathetic weakness
46 (*d*)	Same case, three days later. Well, no vomiting for two days (cocaine and adrenaline)	Rs > L. Rs < L. Rs < L. Rs < L. Rs < L.	Right sympathetic lesion or left third palsy probably still present. Tests really inconclusive. Interval since last application too short

A right cerebellar astrocytoma was examined (Case 48). It will be seen that a difference in reaction of the pupils is not taken as evidence of a third nerve palsy, as it can occur markedly in a sympathetic weakness.

Case No.	*Clinical diagnosis*	*Results of tests*	*Comment on results*
48 (*a*)	Right cerebellar astrocytoma. Slight enophthalmos right	R < L. eR < L. eR < L. eR < L. R < L.	Probably a right peripheral sympathetic "degeneration." Right pupil during test reacted more briskly than left
48 (*b*)	Same case tested with pilocarpine	R < L. R < L. R < L. R < L. R < L.	Tests consistent with right sympathetic weakness
49	Glioma of tip of right temporal lobe, extending forwards	R = L. R = L. Rs > L. R > L. R > L.	Right third nerve paresis
51 (*a*)	Left sphenoidal wing meningioma, extending mainly backwards	R = L. Rs > L. Rs > L. Rs > L. Rs > L.	Left sympathetic "degeneration," but tests really not conclusive of anything
51 (*b*)	Same case, tested with pilocarpine	Rs > L. R > L. R > L. R > L. R > L.	Tests suggestive of a left sympathetic weakness. (This patient after operation developed severe hypothalamic disturbance, and hemiplegia)

In addition to the tumours above, an acoustic neuroma was examined, showing doubtful evidence of a homolateral sympathetic lesion

An old suppurative otitis media was seen and gave results consistent with a homolateral third nerve palsy (cf. Case 20 in Group B III).

Case No.	*Clinical diagnosis*	*Results of tests*	*Comment on results*
66	Old suppurative otitis media, right. No active symptoms now	R = L. Rs > L. R > L. R > L. R > L.	Evidence of right third nerve paresis

One clear case of an irritative lesion of the sympathetic system was seen. It gave equal dilatation with the collyria.

Case No.	*Clinical diagnosis*	*Results of tests*	*Comment on results*
65	Swelling of right parotid gland one year. On section no abnormal histology seen. Hyperhidrosis right face, wider palpebral fissure, right	R > L. R = L. R = L. R = L. R > L.	An irritative lesion of the right sympathetic system

Two subdural hæmatomata were seen in late stages, once surgery had been successfully exhibited, and collyria could no longer obscure the picture. The results are given below; they are not conclusive.

Case No.	*Clinical diagnosis*	*Results of tests*	*Comment on results*
45	Left subdural hæmatoma	R > L. R > L. Rs > L. Rs > L. Rs > L.	No real evidence of third nerve palsy. ? left preganglionic sympathetic lesion, or left third nerve irritation
50	Right subdural hæmatoma, one month after operative removal of blood	R < L. R < L. R < L. R < L. R < L.	A right sympathetic "degeneration," or a left third nerve weakness

Of the remaining 4 cases, 2 were taken to be third nerve weakness (a post-encephalitic Parkinsonism with diplopia and a disseminated sclerosis).

Two showed no evidence of nerve lesion (a pinealoma and a ? hysterical convergent strabismus).

Discussion.

The interpretation of third nerve weakness is fairly straightforward, depending upon regular dilatation in both eyes and an increased pupillary difference. Sympathetic "degeneration" in the cases here described shows itself by a poor dilatation of the affected eye with irregularity or eccentricity of the pupil. Attention is drawn particularly to Case 54, Group B VI. This case shows an anomalous dilatation interpreted by Magitot and others as abnormal sensitivity to adrenaline, yet to these collyria it shows a diminished and abnormal response. It would seem that the anomalous dilatation is more likely due to a central relaxation of the sphincter.

Interpretation of both states depends on a high degree of efficiency of the test on a control series. Even cutting out all pathological explanations for abnormalities, the coefficient of efficiency reaches 90 per cent.

In conclusion the test is of use in the following cases:

(*a*) Where the side of the lesion is known, the cause of the inequality can be determined, probably even when it is complex, as in aneurysm cases.

(*b*) Where the side is not known but the system involved is known, the nature of the lesion can be determined, even in anomalous cases.

Diagnosis is not possible, however, between transient sympathetic block and a sympathetic stimulation of the other side. In both the inequality disappears. Third nerve stimulation cannot be more than suspected from a persistent but not increased difference. Differentiation between slight degrees of parasympathetic block and parasympathetic stimulation of the other side can be carried out with probability.

(*c*) Where neither the affected side nor the system involved is known, the nature of the lesion can be determined with confidence in a well-marked third palsy and an old-standing organic sympathetic palsy. In both the difference is increased, but in the former the pupils remain round

and both respond by dilatation: in the latter the affected pupil remains small and becomes irregular.

For finer diagnosis, the remarks under (*b*) above apply, with the addition that one cannot more than suspect which system is involved.

Summary.

A test is described using cocaine and adrenaline drops to elucidate the underlying cause in cases of pupillary inequality. The anatomical and pharmacological basis for the test is discussed, and the reasons for the selection of this solution. A series of 66 cases of pupillary inequality due to various causes is summarized, with the results of the test, and the suggested interpretations. A series of 50 normal controls is also described.

It is claimed that the test is of help in determining in any given case the cause of a pupillary inequality and can bring out a latent inequality if so desired.

The tests suggest that the commonest cause of pupillary inequality in recent head injuries is a partial third nerve paresis, which may affect the pupil without there being any demonstrable external ophthalmoplegia.

An old-standing case of Horner's syndrome also gives a typical result, and this may be of considerable value in its application to cases of intracranial aneurysm.

Other cases, including several intracranial tumours, are described with the results of the test.

Except where the diagnosis has been queried in the tables of results it has been established beyond all reasonable doubt.

My thanks are due to Mr. James Eric Paterson, of the Neurosurgical Unit at Killearn Emergency Hospital, who first set me on the path of investigation of pupillary inequality and in whose unit the work was begun. But for his continued help and encouragement it would never have been completed. Most of the cases were examined and tested in a Military Hospital for Head Injuries, and I am indebted to the Commanding Officer for his permission to publish results of work done on his cases.

Photographs.

It is not necessary to adopt the complicated methods described by Löwenstein and Westphal in order to secure still photographs of the pupils. The following photographs were taken by firing off a flash bulb while the camera aperture was held open. The duration of the light is too short for the pupil to react while it lasts, and before the flash any desired form of illumination can be used.

PLATE VI.

a

b

c

FIG. 1.

To illustrate article by Eric A. Turner.

PLATE VII.

a

b

FIG. 2.

a

b

FIG. 3.

To illustrate article by Eric A. Turner.

The camera employed was a Leica, fitted with reflex housing, using a 13·5 cm. lens in a 35 mm. extension tube. The flash bulbs were "Baby Sashalite," designated "long flash" (1/40th sec.). The camera was placed 21 inches from the subject, focused carefully, and the photograph taken with f18. It will be seen that focusing is so fine that the nose can be out of focus while the eyes are sharp.

For the photographs I am indebted to Pte. Tugwell, E. L., R.A.M.C., who drew my attention to this simple method of securing an accurate and permanent record of cases of special interest.

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LEGENDS.

FIG. 1.—A case of third nerve paresis (parasympathetic supply to the pupil) in the right eye. Now recovering. Inequality practically gone. (*a*) Before application of any drops; (*b*) fifteen minutes after cocaine and adrenaline drops; (*c*) thirty minutes after the drops. Note that the inequality is increased by the drops.

FIG. 2.—A case showing no evidence of parasympathetic paresis. A transient inequality had probably been due to a temporary sympathetic disturbance. (*a*) Before application of drops; (*b*) thirty minutes after application of cocaine and adrenaline. Note the wide, equal dilatation.

FIG. 3.—A case showing left sympathetic disturbance with non-response to the drops in the left eye. (*a*) Before application of drops; (*b*) thirty minutes after application of cocaine and adrenaline. Note the irregular dilatation. The smaller pupil is now the larger—a case of anomalous dilatation. The other possible cause for such an anomalous dilatation is a combined lesion on the right side.

THE ADIPOSE TISSUE OF PERIPHERAL NERVES.

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It is well recognized that fat often forms a conspicuous element of the interfascicular tissues of the larger nerves. In a recent investigation devoted to a study of the intraneural vascular and fasicicular patterns, microscopic sections from all levels of a large series of normal radial, median, ulnar and sciatic nerves were examined. In the course of this study it was observed that the interfascicular adipose tissue varied in amount not only in different nerves in the same individual but at different levels along the same nerve. Furthermore, the amount of fat was not always related to the obesity, or otherwise, of the subject though in general the nerves of the obese did contain more fat than those of the lean. Reference to the relevant literature failed to provide any information on these points.

The object of this paper is to direct attention to the variable character, and possible significance, of the interfascicular adipose tissue of peripheral nerves.

Material.

Observations were made on histological preparations of the radial, median, ulnar and sciatic nerves in forty adult dissecting-room and post-mortem specimens which included the right and left nerves from ten subjects. Segments were taken from the four nerves at all levels and, after fixation and embedding in the usual manner, sections were cut at 25 μ and stained with osmic acid and eosin and hæmatoxylin.

Observations.

In order to compare the amount of fat present in transverse sections of the nerves the quantity of this tissue relative to the total cross-sectional area of the nerve has been arbitrarily classified as marked, intermediate or insignificant. The meaning ascribed to each term is illustrated in the accompanying microphotographs (figs. 1, 2, 3, 4 and 5). The differences between each group, on the basis of this simple classification, are so marked that it is a relatively simple matter to assign each section to one or other group. It is believed that, for the purposes of this investigation, any further refinement of classification is unnecessary.

Radial, Median and Ulnar Nerves.

In general the fasciculi of the radial, median and ulnar nerves were compactly arranged and the interfascicular adipose tissue reached significant proportions in only 41 per cent. (marked 10 per cent., intermediate 31 per cent.) of the specimens (fig. 1). When present this fat predominated in certain regions such as in the median nerve in the upper arm and in the radial nerve in the spiral groove where the fasciculi of the latter are loosely arranged in areolar supporting tissue. There was no significant difference in fat content between the median and radial nerves. Adipose tissue was never marked in amount in the ulnar nerve and rarely reached intermediate proportions in the nerves in the forearm.

Sciatic Nerve and its Popliteal Branches.

(1) The amount and distribution of the interfascicular adipose tissue in the sciatic nerve and its medial and lateral branches, in the 40 specimens examined, was as follows: —

	Marked	Intermediate	Insignificant
Buttock	59 per cent.	18 per cent.	23 per cent.
Mid-thigh	64 per cent.	18 per cent.	18 per cent.
Distal third of thigh			
Medial popliteal N.	50 per cent.	32 per cent.	18 per cent.
Lateral popliteal N. ...	50 per cent.	5 per cent.	45 per cent.

Thus the sciatic nerve contained appreciable quantities of fat in a high proportion of specimens and in this regard differed from the nerves of the upper limb. The medial and lateral popliteal branches contained less fat than the main trunk while this tissue was insignificant in amount in the lateral popliteal nerve in almost half the number of specimens examined.

(2) When present the fat was disposed either between the two principal divisions of the sciatic nerve, between the fasciculi of the individual divisions, or in both situations.

(3) The distribution of the fat appeared to favour the medial division of the main trunk. This was particularly noticeable in high divisions of the sciatic nerve where in 6 specimens the quantity of fat was marked in the medial division but absent or insignificant in amount in the lateral divisions.

(4) Attention is directed to the large number of specimens in which the lateral popliteal nerve contained little or no fat. One of the factors determining the greater vulnerability of the lateral division in injuries of the sciatic nerve and the susceptibility of the lateral popliteal nerve to

compression at the neck of the fibula may well be the lack of an enveloping viscous supporting medium about the fasciculi.

(5) Adipose tissue was more frequently present and was greater in amount in the buttock and thigh.

(6) The amount of adipose tissue usually, but not invariably, bore a direct relationship to the general obesity of the subject.

(7) The quantity of adipose tissue occasionally varied at different levels along the same nerve (Table I and figs. 2*b* and 5) and at corresponding levels on the two sides of the body in the same individual (Table I and figs. 4 and 5).

TABLE I.—The dimensions of (transverse diameters in millimetres) and quantity of fat present in the sciatic nerves of two subjects.

Specimen	*Sciatic nerve*		*Med. popliteal N.*	*Lat. popliteal N.*
	Buttock	*Mid thigh*		
6 Right ..	12 × 6 Fat marked	12 × 4 Fat marked	7 × 5 Fat intermediate	6 × 3 Fat insignificant
6 Left	9 × 5 Fat insignificant	11 × 4 Fat marked	6 × 4 Fat insignificant	5 × 3 Fat insignificant
8 Right ..	13 × 5 Fat insignificant	12 × 6 Fat marked in medial division	10 × 8 Fat marked	6 × 3 Fat insignificant
8 Left	16 × 5 Fat intermediate	11 × 4 Fat intermediate	10 × 7 Fat marked	7 × 3 Fat insignificant

(8) Computations of the cross-sectional area of the nerves at different levels and in different subjects demonstrated that a relationship existed between the amount of fat present and the thickness of the nerve—the greater the quantity of interfascicular fat the thicker the nerve, and vice versa (Table I). However the relationship was not a proportionate one since other mesenchymal elements and the size of the limb are of importance in this regard.

COMMENT.

It would appear that the function of interfascicular adipose tissue is to protect the nerve by acting as a buffer or cushion for the fasciculi. In this connection it is interesting to note its predominance in the sciatic nerve in the buttock and thigh, two regions where the nerve is habitually subjected to pressures and strains not experienced by other nerves. Since the lateral popliteal nerve is not normally subjected to strain or pressure at the neck of the fibula the lack of the adipose protective element at this

site is accounted for though its absence does predispose the nerve to compression injuries.

Observations suggest that when general wasting occurs the intraneural fat behaves in the same way as does the general fatty tissue elsewhere in the body. With the decrease of interfascicular adipose tissue the nerve is deprived of one of its protective and supporting elements and, since the general tissues surrounding it have been correspondingly affected, the fasciculi are less protected and consequently more liable to injury from pressure and traumata.

Large amounts of interfascicular fat usually result in a dispersal of the fasciculi which may be one of the local factors influencing the degree to which individual fasciculi in the trunk may be traumatized.

Furthermore when a nerve is sutured the chances of obtaining end to end apposition of corresponding fasciculi, which facilitates regeneration and minimizes the cross-shunting of regenerating axons, diminish as the dispersal of fasciculi increases. Again, where spontaneous regeneration follows the intraneural rupture of fasciculi the risk of deflection of regenerating axons into interfascicular spaces is increased if the fasciculi are widely separated. The accompanying figures (4 and 5) will illustrate these points.

When the nerve is composed of tightly packed fasciculi (fig. 4) approximation of the nerve ends means that fasciculi in the proximal segment will be opposed to fasciculi in the distal segment even though the apposition may not re-establish continuity between corresponding fasciculi. If, on the other hand, the fasciculi are widely separated (fig. 5) then it is not unlikely that when the nerve is sutured the cut ends of the fasciculi in the proximal segment will be directed towards the interfascicular tissues of the opposing segment. Under these circumstances the possibility of cross-shunting between fasciculi is increased, while many regenerating axons will end blindly in the interfascicular spaces. The end-results following suture of the sciatic nerve are frequently unsuccessful and, though other factors are known to operate in adversely influencing the end-results of suture, a contributing cause may well be a wide dispersal of fasciculi in that nerve.

Summary.

(1) The amount and disposition of the interfascicular adipose tissue has been investigated in 40 specimens of the radial, median, ulnar and sciatic nerves.

(2) Attention is directed to the variable character of this element in

nerves from the same and different subjects, on the two sides of the body and at different levels along the same nerve.

(3) The sciatic nerve contained appreciable quantities of fat in a high proportion of specimens and in this regard differed from the nerves of the upper limb where this tissue reached significant proportions in less than half the specimens.

(4) The medial and lateral popliteal nerves contained less fat than the sciatic trunk while in half the number of specimens examined the lateral branch contained very little, if any, fat.

(5) The function of this intraneural adipose tissue and its possible influence on regeneration in sutured nerves are briefly discussed.

LEGENDS TO ACCOMPANY FIGURES

FIG. 1.—Transverse section of the median nerve in the forearm to illustrate the compactly arranged fasciculi and the almost complete absence of fat between them. X10.

FIG. 2.—Transverse sections of the sciatic nerve in two subjects at corresponding levels in the buttock. (*a*) Fat marked in amount and dispersing the fasciculi. X4. (*b*) Fat insignificant in amount and the fasciculi more compactly arranged. X5.

FIG. 3.—Transverse sections of the sciatic nerve in two subjects at corresponding levels in the mid-thigh. (*a*) Fat marked in amount and dispersing the fasciculi. X3·3. (*b*) Fat moderate in amount between the divisions but insignificant between the fasciculi. X6.

FIGS. 4 and 5.—Transverse sections from the right (fig. 4. X8) and left (fig. 5. X5·5) medial popliteal nerves at approximately corresponding levels in the same subject to demonstrate the variation in fat content on the two sides of the body and the dispersal of the fasciculi which occurs with the increase in fat content.

PLATE VIII.

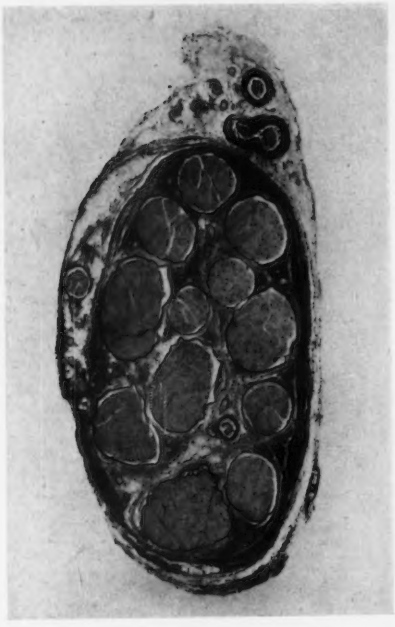


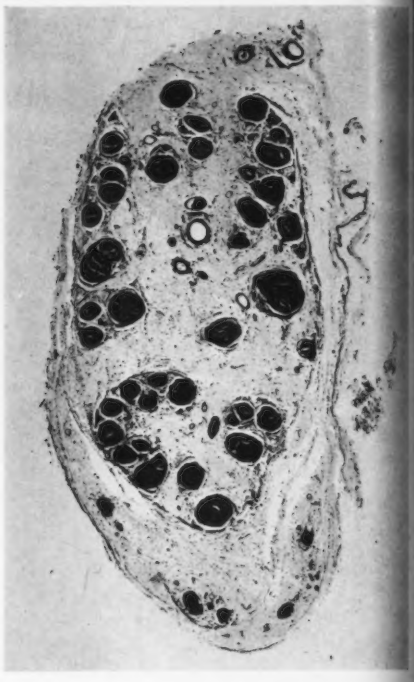
FIG. 1.

a FIG. 2. *b*

To illustrate article by Sydney Sunderland.

PLATE IX.

a



b

FIG. 3.

FIG. 4.

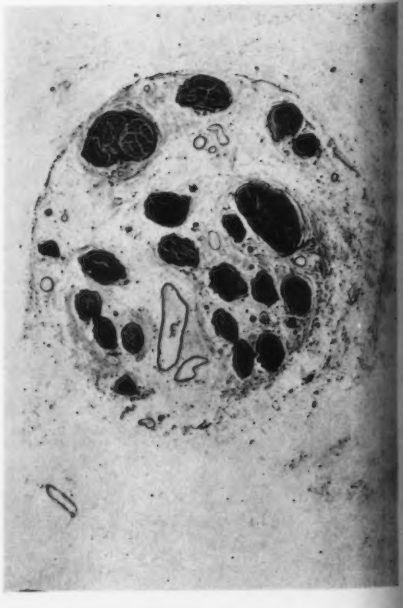


FIG. 5.

To illustrate article by Sydney Sunderland.

ABNORMAL SUPPRESSION OF CORTICAL FREQUENCIES.[1]

BY DENIS WILLIAMS AND JOAN REYNELL.

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WHEN brain is damaged, abnormally slow waves make their appearance in the electroencephalogram (E.E.G.). These abnormally slow waves arise in the damaged area, their voltage and persistence are directly related to the severity of the damage, and their frequency is indirectly related to it. These slow waves are the direct result of damage to cortical tissue, and they do not necessarily reflect the nature of the destructive agent, although evaluation of all the changes seen in the E.E.G., with all other clinical evidence, may lead to a reasonable conclusion upon the nature of the causal lesion. Other changes in the E.E.G. which may result indirectly from cerebral damage have features indistinguishable from dysrhythmias associated with inborn disorders such as idiopathic epilepsy or other behaviour disturbances (Williams, 1944). The great bulk of the literature upon the E.E.G. in abnormal states—whether resulting from inborn or hereditary causes or the result of an acquired disorder—deals with these abnormal waves. This literature has been adequately reviewed elsewhere (Lindsley, 1944).

Much less attention has been paid to the negative effects of cerebral dysfunction, that is to the inhibition or absence of waves of electrical potential change which may be seen in abnormal states. Isolated observations have been made upon single cases, but these have been incidental to reports dealing with the abnormal waves characteristic of cortical damage. Martin and Williams (1939) reported the finding of a large "silent area" in the E.E.G. records of an epileptic youth who had a porencephalic defect of the brain in the left parieto-occipital area. The finding of the "silent area" led to the diagnosis of porencephaly, and an air encephalogram showed that the position of the "silent area" corres-

[1]The use of the word "suppression" has been criticized. Many alternatives, which need not be quoted, have been discussed and rejected. In using the word, it must be remembered that while the suppressing agent may still be active, more usually it is not, although its results continue. In either case these results may be total or partial, and the suppressing factor may sometimes be inherent in the phenomenon suppressed. In the present context there are many causes of suppression and many circumstances in which it has occurred. Even in the extreme case where loss of cortex has caused absence of the appropriate frequencies, the initial pathological process suppressed those frequencies.

ponded closely with that of a large brain defect which communicated with the posterior horn of the left lateral ventricle. Jasper, Kershman and Elvidge (1940) recorded similar "silent areas" from the scalps of patients with subdural hæmatomas, and offered an explanation for the phenomenon. Later, Jasper (1941) described similar findings from the scalp of an epileptic patient who had undergone excision of an area of cortex from which epileptic discharges had originated. In this case also the position of the "silent area" corresponded with the site of the excised brain tissue. Case (1940) described a series of eight patients with homonymous hemianopia who showed relative suppression of normal "alpha" waves in the contralateral hemisphere, and concluded that "unilateral loss of occipital 'alpha' waves or gross difference in the size of these waves constitutes a sign of signal importance in the diagnosis of lesions of the temporal or occipital lobes." Kornmüller has recently (1944) described diminution in the size, regularity and continuity of the alpha rhythm, and he also has stressed its value as a sign of local brain damage.

Apart from these observations upon localized suppression of cortical frequencies there have been reports of generalized suppression in abnormal states. This abnormal change should be considered in sharp distinction from that which occurs temporarily as a result of physiological changes such as visual stimulation (Adrian and Matthews, 1934), attention or concentration, auditory or other stimulation (Loomis, Harvey and Hobart, 1936), sleep, or changes in blood constituents (Davis, 1941). It should also be kept distinct from the inhibition which can be induced by conditioning (Jasper and Shagass, 1941, Shagass, 1942), or by states of abnormal tension (Berger, 1935), the mechanism of which must surely be the same as that operating in the more usual circumstances of inhibition which have been mentioned. The nature of this normal suppression of "alpha" activity has been discussed by Adrian (1944). Generalized and pesistent suppression of normal frequencies is found when slow waves of cerebral damage are present (Jasper, Kershman and Elvidge, 1940; Williams, 1941), and it also occurs immediately after cerebral concussion, whether this is produced experimentally in animals (Williams and Denny-Brown, 1941) or accidentally in man. Case (1938) noted the suppression of normal activity associated with abnormal slow waves in a series of cases of cerebral tumour. In these circumstances, the degree of suppression of the normal frequencies is often inversely related to the degree of prominence of abnormal slow waves, and when these have subsided, return of the normal frequencies constitutes the last stage of recovery of the E.E.G. recorded from injured brain (Williams, 1941).

Jasper, Kershman and Elvidge (1940) pointed out that the variability in the amount of "alpha" activity seen in the normal individual makes the assessment of such a change difficult, and they observed that suppression of normal frequencies was not considered a certain indication of abnormality unless it was asymmetrical in the hemispheres.

Abnormal suppression of cortical frequencies has received relatively little attention because it is usually associated with abnormal slow waves which tend to dominate both the record and the attention of the observer, and also because the presence of suppression may not be apparent if it does not occur asymmetrically or locally. Since D-day, so many penetrating head wounds have been seen by us, which showed local or unilateral suppression of frequencies—a finding which is in sharp contrast to previous experience—that we have studied the matter in some detail. It is the purpose of this paper to report the results of this study.

Method.

Material.—During the war, clinical abstracts and E.E.G. reports have been indexed for a little over 10,000 abnormal subjects and 350 normals investigated in an R.A.F. unit. As well as the abstracts and reports, E.E.G. records are available on all patients, and full clinical notes on most. From this mass of material all subjects in whom pathological suppression of the cortical frequencies has been observed have been collected, and selected groups of subjects have been isolated for special study. These selected groups have included normals, patients with closed head injuries, injuries penetrating the dura, gunshot wounds without penetration of dura, hemiplegic patients with visual field defects, patients with cerebral tumours, abscesses, subdural hæmatomas, intracranial cysts or angiomas, and patients with tantalum and acrylic repair of skull defects. Whenever cases of this sort were selected for study the E.E.G. records were re-examined and the clinical notes reviewed. In the past year the E.E.G. of cases of head injury, both closed and penetrating, with suppression of cortical frequencies have been studied in detail.

Recording technique.—Three-channel and six-channel ink-writing electroencephalographs (Grass) have been used. The subjects were sitting or lying at rest, and saline pad electrodes were used. The six-channel apparatus which has been used for most of the work has the great advantage that simultaneous records may be obtained from three separate symmetrical areas on each hemisphere. This makes comparison simple and the recognition of an area of relative suppression fairly certain. The details of the technique of recording have been described previously (Williams, 1941*a*). As a rule, four rows of four electrodes each were placed over the head in antero-posterior lines, each adjacent pair of electrodes being used for "bipolar" recording. These simultaneous records were obtained from the frontal, fronto-parietal, parietal and parieto-occipital areas on each side, at one time of recording in a line 2 in. from the midline, and at the next in the line of the Sylvian fissure. When a "silent area" or other focal disorder was found, further examination was made with paired electrodes in other symmetrical positions, and sometimes additional information was obtained by using single electrodes on symmetrical points with common electrodes on the ipsilateral ear. Records from corresponding areas on each side were traced by adjacent pens to aid comparison.

When abnormal suppression of activity was suspected, care was taken to check the inter-electrode distances and the electrode-tissue resistance, and in every case the recording amplifiers were switched to the electrodes on the other hemisphere in order to exclude possible differences in mechanical or electrical amplification. This last possibility was further obviated in every case by the routine simultaneous calibration of amplifiers before recording began. As far as possible amplification was kept constant for the whole series of cases, and paper speed was always 1 in. a second.

Interpretation of records.—Interpretation was by direct visual analysis of records. Automatic electrical analysis of simultaneous records from symmetrical areas would have been simpler and would have revealed small differences in the occurrence of different frequencies which might not be apparent to the unaided eye. Such analysers are not yet available. Comparison between the amounts of energy in different frequency bands in the two hemispheres at different times has been made with such an analyser by Gibbs (1942). Investigators of the distribution of the normal cortical frequencies have compared the " per cent. time alpha"—that is the proportion of time in a stretch of record occupied by the normal 8 to 12 cycle rhythm in different areas (Rubin, 1938 and 1940) using a minimum arbitary voltage of the "alpha" activity to be measured. Such a convention although open to criticism is essential if records which are made at different times are to be compared. When simultaneous records obtained with the same technique from symmetrical points are used, it is possible to compare the frequency, voltage, and number of waves in any wave band. Comparison was made between frequencies with an error of 0·25 cycle. The product of these two characteristics, voltage and number, can be fairly accurately compared, and with practice it is possible to make this comparison visually and to detect differences down to about 10 per cent. The degree of persistent suppression in the cases described in this paper was at least 20 per cent. of the normal side, a difference which when persistent is readily detected by measurement or by direct comparison, but it was usually much greater (fig. 1). Any such persistent asymmetry greater than 20 per cent. is very uncommon in normal subjects although it is said that there is a tendency for the normal rhythms to be slightly less evident in the dominant hemisphere (Raney, 1939). The minimum degree of persistent suppression recognized in this present series (usually about 20 per cent. of the normal side) so rarely occurs without a demonstrable cause that it is considered well beyond the bounds of normality. It has never been seen by us in the E.E.G. from 350 normal subjects (*vide infra*). We wish to emphasize that this study deals with persistent reduction in amplitude and not with transitory differences between the two sides, such as have been studied by Kornmüller (1944).

In comparing the two hemispheres, factors which might cause spurious asymmetry had to be recognized. Those caused by faulty technique have been mentioned and were excluded. Absence of bone will cause an increase in the voltage of waves recorded from its neighbourhood, while a non-conducting graft may have the opposite effect. These phenomena will be described later. As far as possible allowance was made for them in interpreting records in cases where they were encountered.

For brevity, an area from which persistent suppression of electrical activity was recorded will be called a "silent area." There is rarely complete electrical silence in these areas, and even if the E.E.G. failed to show any electrical activity there might still be, and probably would be, activity in individual cells. The term "silent area" will be used with these reservations. "Suppression" refers to reduction as well as total inhibition of this activity.

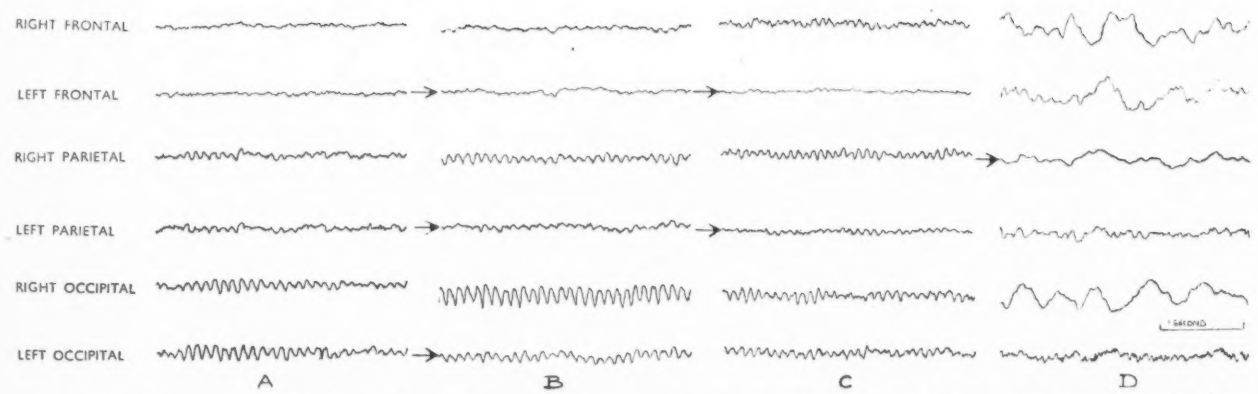

FIG. 1.—Examples of different kinds of electroencephalograms described in the text. The four examples are recorded from the same positions on the scalp with the same amplification and paper speed. The arrows pointing to the record show suppression.

(A) *Normal.*—The dominant frequency of 10 a second is well seen in the occipital regions and attenuates in the parietal and frontal leads. It is symmetrical.

(B) *Unilateral suppression.*—The dominant frequency has a lower voltage in all leads on the left side as a result of a penetrating head injury.

(C) *Focal suppression of normal rhythms.*—The dominant frequency is absent in the left frontal lobe, much diminished in the parietal but nearly symmetrical in the occipital regions, the result of a frontal penetrating wound.

(D) *Focal suppression of abnormal rhythms.*—High voltage 2 and 3 a second waves, most evident on the right side, are suppressed in the right parietal region. The abnormality was the result of a severe closed head injury with a right parietal depressed fracture.

Results.

Normals.—No evidence of significant persistent asymmetry in the normal or abnormal rhythms was seen in the 350 normal subjects. Simultaneous records from both hemispheres in the last 100 of these subjects were examined with care and in no instance was a persistent asymmetry of more than 20 per cent. seen. This confirms Raney's observations (1939), but we were unable to detect a persistent difference related to the subject's right or left-handedness. By waveband analysis, Gibbs (1942) has shown that there may be slight differences between the two sides from time to time in different frequency bands. Examination of his records shows that these differences in the product voltage x number of the affected frequencies are usually less than 10 per cent. In this enquiry we are dealing with persistent suppression, not of any one frequency, but of all the normal frequencies, and of abnormal frequencies if they are present. As this has not been seen in normal subjects it simplifies the study of the abnormal groups.

Head Injuries.

Penetrating head injuries.—When acute penetrating head wounds became available for examination in large numbers after D-day, the records seen contrasted strikingly with those previously obtained in so many cases of closed head injury. In general, widespread slow activity of the sort already described in closed injuries (Williams, 1941, *a* and *b*) was less evident, and although focal slow waves were found at or near the site of injury, these were often associated with suppression of all activity at this point. In a series of 90 consecutive penetrating head injuries examined, a "silent area" was present at the time of recording in 27 (30 per cent.) while focal slow waves around the area of penetration were found in 49 (55 per cent.). Generalized abnormality was present in only 12 (13 per cent.), while 17 (19 per cent.) had normal records. Nearly a half of the patients with focal slow waves also showed a "silent area" in the same neighbourhood, usually in the centre of the area of abnormality. Sometimes the area of suppression was surrounded by an area from which slow waves were recorded, but in this respect a distinction could be made between the E.E.G. recorded before and after operation. Whereas slow waves were present around the damaged area before operation, it was common within a week of toilet of the wound and removal of damaged brain to find simply suppression of activity with little or no abnormally slow wave forms. This finding was remarkable in view of the severe damage to brain tissue present in these cases. 46 patients with pene-

trating wounds of the brain in the neighbourhood of which there was suppression of frequencies were consequently subjected to special study. In this group the time of the first record after the injury varied from three days to six months, but it was usually one to three months. Five of the injuries were frontal, 15 parietal, 13 occipital and 13 temporal. The frontal lobe was involved in only about a tenth of the cases with "silent areas," although frontal penetration by missiles is common. This discrepancy may have been because the frontal lobes usually show little "alpha" activity so that except in special circumstances pathological suppression could not be recognized.

Degree of brain damage.—In 38 of the 46 cases (83 per cent.), the "silent area" in the E.E.G. was considered on the clinical evidence and operative findings to be due to complete destruction of brain substance. In 2 of these cases brain had been replaced by a traumatic cyst. In the 8 cases where brain damage seemed to be superficial and slight the suppression appeared to be related to local contusion of brain which was followed by rapid recovery of function. Case 8686 is an example of a penetrating injury with gross loss of brain tissue. This loss of tissue was observed at operation and confirmed by clinical examination and electroencephalography.

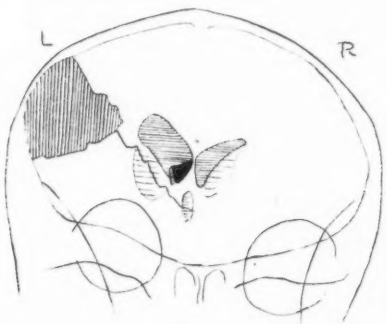

FIG. 2.—Tracing of the ventriculogram of Case 8686. The left ventricle is enlarged and drawn towards the large bone defect which is shaded. A metallic foreign body is shown in black.

Case 8686.—A fusilier, aged 19, received a gunshot wound in France in July, 1944. He had a penetrating wound of the left parietal lobe. There was a large posterior parietal bone defect, many bone fragments were deeply indriven, and a metallic foreign body had traversed the hemisphere and lay against the falx. He was admitted to the hospital in coma with a right hemiplegia. Next day he was in semicoma. The wound was excised and indriven bone and damaged brain were removed. When he could co-operate a complete right hemiplegia and hemi-

anæsthesia with hypalgesia was found, and he had executive aphasia. There was also a right homonymous hemianopia. Recovery from the acute stage of the injury was satisfactory, but he had persistent neurological evidence of widespread destruction of brain tissue in the left parietal lobe. An air encephalogram six weeks after injury showed marked general dilatation of the left lateral ventricle particularly of the body. Here the ventricle was drawn out towards the bone defect, confirming the loss of brain tissue (fig. 2). He was invalided six months after injury. He then had an incomplete right homonymous field defect, a severe spastic right hemiplegia and profound sensory loss on the right, with impairment of pain sensation, and a residual dysphasia.

E.E.G.—Records were persistently abnormal during the six months in hospital. At the end of this time abnormality was still present in the left hemisphere. The dominant frequency was reduced throughout the hemisphere, medium voltage 2 to 6 a second waves could be recorded from the environment of the bone defect, although underneath it their voltage was lower, and episodes of pathological fast activity had also developed in this region (fig. 3). These records indicated the

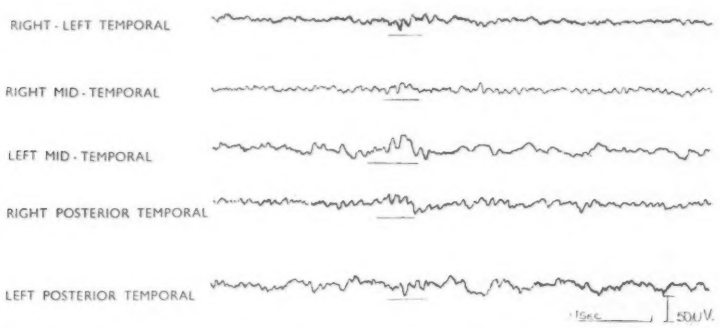

FIG. 3.—E.E.G. records from Case 8686. The normal rhythms are suppressed in the left mid-temporal lead, and irregular 2 and 3 a second waves are seen arising from the left side. A short episode of high voltage abnormal waves is also present; this is underlined.

persistence of abnormal brain tissue, around an area of complete loss of brain substance, with the development of secondary changes, the precursors of an epileptic state.

Comment.—This is an example of extensive damage and destruction of brain tissue confirmed by air encephalography. Abnormal brain, persisting six months after the injury, gave characteristic direct and indirect changes in the E.E.G. (Williams, 1944). A "silent area," persisting for six months after injury, was due to complete loss of an extensive area of cortex.

The cases of focal contusion without evidence of brain destruction were similar to those described in the section on closed head injuries, and the E.E.G. findings were identical. In these cases there was progressive

return of normal frequencies in the affected area as recovery took place. Cases of this sort in which recovery was presumed to have occurred before the first E.E.G. record, other cases with penetrating wounds causing limited destruction of brain, and wounds involving the anterior parts of the frontal lobes, were included in the group of penetrating head injuries in which there was no evidence of focal suppression of frequencies at the time of recording. Experience with other cases showed that had records been made sooner after the injury, suppression may well have been observed in some of them.

Position of brain damage.—The degree, position and extent of local suppression of *normal* rhythms depended upon the site of injury rather than its severity, whereas the degree and extent of suppression of the *abnormal* waves caused by the injury was determined by the severity of

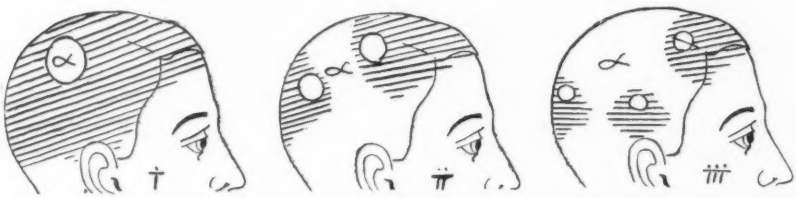

FIG. 4.—Diagram of the effect of lesions in different positions upon the alpha rhythm: (i) A lesion involving the site of origin of the rhythm causes widespread suppression; (ii) lesions near the site of origin cause suppression in their neighbourhood and distal to them; (iii) lesions at a distance from the focus cause focal suppression only.

the injury alone. The effect of site of injury upon normal rhythms may be summarized as follows:—

Frontal injury (5 cases)—caused local suppression around and in front of the injury. In many other cases absence of activity in the frontal lobe may have obviated changes of this sort.

Posterior parietal injury (10 cases)—caused suppression throughout the affected hemisphere.

Occipital injury (13 cases)—caused local suppression only, but if the wound involved the parieto-occipital region the suppression affected the whole hemisphere.

Temporal injury (13 cases)—caused local suppression only.

The areas of suppression and sites of injury were charted for each case, and the grouped results are shown in fig. 4. The conclusions which were reached from these observations were that damage to the focus of origin

of the normal dominant frequency caused complete suppression of these waves throughout the hemisphere, while damage elsewhere simply interrupted the propagation of those waves, so that there was suppression at the site of injury and beyond it, away from the focus of origin. The limitations in localization imposed by recording through the intact scalp prevented any more detailed conclusions. It follows from these observations, however, that widespread inhibition of normal frequencies causing a large "silent area" does not necessarily indicate extensive brain damage.

Relation to visual field defects.—The visual fields in all cases with homonymous defects were compared with the degree of suppression of the normal frequencies. In general there was a direct relationship between the size of homonymous field defects and the intensity and extent of the suppression.

Homonymous field defect	*No. of cases*	*Per cent. with suppression of frequencies*		
		None	*Focal*	*General*
Complete	19	10	48	42
Quadrantic	23	43	27	30
Scotomatous.. ..	10	90	0	10

The relationship between generalized suppression and a field defect was so close that it seemed possible that the suppression might have been directly due to the interruption with the function of visual pathways in the affected hemisphere as has been postulated by Case (1942). This was found not to be so, for a complete homonymous hemianopia due to radiation damage caused by a severe temporal wound in Case 7658, and by a very small occipital wound in Case 7629, showed only local suppression, while similar fields caused by striatal damage, the result of an occipital and occipito-parietal injury, was associated with complete suppression of the physiological frequencies (Case 7629).

Temporal injury with right homonymous hemianopia.

Case 7658.—An infantryman, aged 26, had a bullet wound just above the left pinna in July, 1944. The missile went inwards and slightly backwards and upwards to a depth of about 3 cm. below the dura. There was no amnesia. When the patient was tested shortly after the injury he had a complete right homonymous hemianopia, splitting the macula. There was an extensor plantar response on the right, without any other hemiplegic signs, and no sensory defect. There was also a nominal dysphasia and dyslexia of mild degree. At operation the next day the wound was excised, a dural defect 1 cm. across was found, and enlarged, and about 5 c.c. of pulped brain were removed with twenty small bone chips. The wound was then closed. The patient made a rapid recovery and three weeks after wounding was transferred to a convalescent home. He then had dysphasia when tired and a right homonymous visual field defect which was slowly recovering in the upper quadrant (fig. 5). In view of the field defect the patient was invalided from the Army fourteen weeks after wounding. He then had a right homonymous

lower quadrantic visual field defect, without any other complaints. When E.E.G.s were recorded *two weeks* after wounding, the homonymous defect was still complete and "there was very slight focal abnormality in the left temporo-occipital region, consisting of low voltage 1 to 2 a second waves which were underlying a symmetrical dominant frequency of 10 a second." *Fourteen weeks* after injury the

FIG. 5.—The site of injury, field defects and E.E.G. of Case 7658. The position of the bone defect is shaded and the metallic foreign body is shown in black. The E.E.G. is virtually normal and shows symmetrical alpha rhythm.

FIG. 6.—The site of the injury, field defects and E.E.G. of Case 7903. The position of the bone defect is shaded. There is suppression of the normal frequencies in the right parietal region. Records also show medium voltage 1 a second waves arising from this area, with generalized medium voltage 3 a second waves.

report read "the focal disturbance in the posterior temporal region on the left has virtually subsided. There are still very low voltage 3 a second waves in this neighbourhood, but there has been considerable improvement in the last two or three months. There is again no change in the physiological dominant frequency" (fig. 5).

Comment.—In this case a homonymous hemianopia was caused by damage to the optic radiation as a result of a small penetrating temporal wound. Localized slow activity was confined to the region of the wound. No suppression of normal frequencies could be found because the cortical damage was confined to a small area and because this area was far removed from the site of origin of the "alpha" frequency in the parieto-occipital cortex.

Parietal injury with homonymous hemianopia.

Case 7903.—An infantry corporal, aged 20, was hit in the right parietal region by a bullet in August, 1944. He remembered the impact. He had received an injury in the mid-parietal position half-way between the mid-line and the ear with dural penetration and indriven fragments of bone. Two days after wounding he was drowsy but co-operative. He had left-sided weakness, a left hemianæsthesia and a complete left homonymous hemianopia. The wound was excised and the damaged brain exposed. Many fragments of bone were removed with pulped brain tissue. The track in the brain was 4 cm. deep and the wound did not involve the ventricle; the superficial area of damage had a radius of about 2·5 cm. Post-operative X-rays showed no bone chips or foreign bodies. After operation progress was steady, and he was sent to a convalescent home five weeks after wounding. At that time there were minimal pyramidal signs, the hemianopic defect had become smaller and mainly involved the left inferior quadrant, but there was profound sensory loss involving pain and temperature appreciation as well as other forms of sensation. He was invalided three months after wounding with persistent sensory loss and a homonymous field defect (fig. 6). An E.E.G. recorded four weeks after injury showed suppression of the normal frequencies over an area around and in front of the bone defect. This was associated with occasional medium voltage 1 to 2 cycle waves arising from the same position (fig. 6).

Comment.—In contrast to the preceding two cases, in this instance a homonymous field defect was associated with focal suppression of normal frequencies. The suppression extended forward from the lesion. The essential difference between the cases was that the injury in this case was closer to the site of origin of the physiological dominant frequency.

Occipital pole injury with homonymous hemianopia.

Case 7629.—An infantryman, aged 21, was wounded in France on July 9, 1944. He had an entry wound in the right occiput, with a depressed fracture underlying it, and a bullet lying superficial to it, its long axis tangential to the skull (fig. 7). At operation two days later the missile was extracted from the scalp, the depressed fracture elevated and the bone fragments removed. The dura mater was intact. The patient was conscious but unco-operative until two days after admission, but when he was more co-operative he was found to have a complete left homonymous hemianopia with macular splitting and slight left lower facial weakness. There

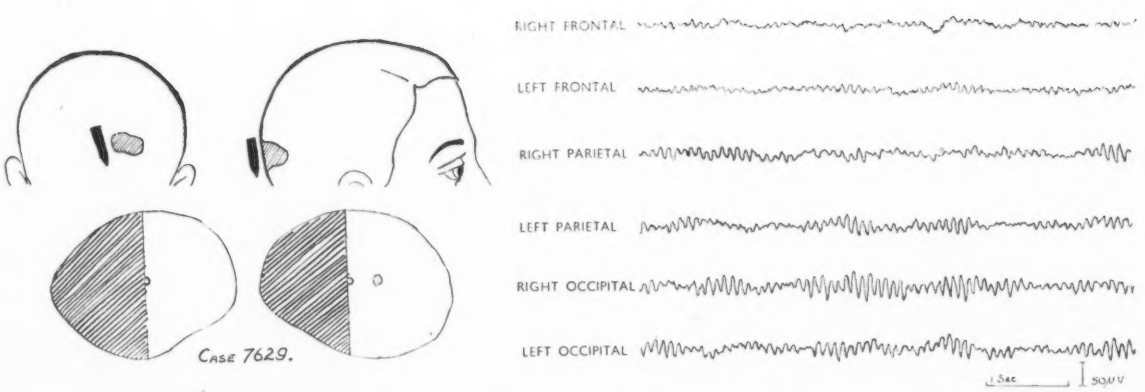

FIG. 7.—The site of injury, field defects and E.E.G. of Case 7629. The bullet is shown in the scalp over the occipital bone, and the bone defect made at operation is shaded. The E.E.G. shows a high voltage frequency of 10 a second. Its voltage is a little higher in the right occipital region than elsewhere because of the bone defect. No abnormally slow waves are present.

was no other evidence of pyramidal damage, and full sensory examination was normal. The man had an amnesia for two days after the accident. Post-operative progress was uneventful except that nine days after wounding he had a *grand mal* attack beginning with twitching of the left side of the mouth. The homonymous hemianopia persisted and became permanent. Because of the hemianopia he was invalided, but he had no other complaints. An E.E.G. recorded twelve days after injury showed "a focal abnormality in the right occipital region consisting of medium voltage abnormal waves with frequencies between 1 and 4 a second which interrupt a symmetrical dominant frequency of 9 a second." Careful search showed no evidence of diminution of the "alpha" waves (fig. 7).

Comment.—In this case a very small and well localized injury of the occipital pole caused a complete hemianopia without asymmetry of the "alpha" waves.

More detailed study of the cases in Table I showed that a complete hemianopia associated with suppression throughout the hemisphere was due to a parieto-occipital injury in 7 out of 8 cases, while the 2 cases without any suppression had injuries to the occipital pole. All the 7 patients with quadrantic defects and generalized suppression on the affected side had parieto-occipital injuries, while the 10 without any suppression had occipital (4), temporal (2) and parietal (1) injuries. Thus the chance of normal "alpha" frequencies being suppressed did not depend purely upon suppression of visual function by a lesion of the optic radiation or the visual cortex, but on the site of the injury which caused both. Case (1942) has stated that suppression of occipital "alpha" activity is caused by a lesion of the optic radiations. The present results do not support his conclusion, but indicate rather that suppression is independent of such a lesion, and is caused by damage to the area of cortex from which the "alpha" waves originate, the association with hemianopic defects being due to anatomical proximity and not to direct physiological relationship. This difference is a fundamental one which will be discussed later.

Since Berger (1935) described the normal persistence of "alpha" waves in a blind person many similar reports have been made. These persons had lost their sight because of disease or injury to the optic nerves or tracts. In the present series cases of blindness resulting from bilateral damage to the optic radiations or the visual cortex have been studied. Cases 9090 and 9219, briefly described below, show that bilateral destruction of the optic radiations does not necessarily result in inhibition of the "alpha" activity. On the contrary they support the observations that have been made on the previous cases, that suppression of these frequencies depends upon damage to the appropriate cortex and not upon interruption of the visual pathways.

Occipital blindness.

Case 9090.—A private, aged 19, received a bi-occipital gunshot wound on March 6, 1945. X-ray showed that a piece of shrapnel had entered over the right occipital pole and come to rest in the opposite temporal lobe, just deep to the pinna (fig. 8). There were 8 pieces of indriven bone. When found he was drowsy and irritable. The pupils were equal and reacted to light, but he seemed totally blind. All limbs moved well, tone was increased on the right, and both plantars were extensor. At operation a day later bone and pulped brain were removed from the right occipital lobe down to the posterior horn of the lateral ventricle. The track was not explored beyond the falx into the left occipital lobe. Three weeks after injury the patient was ambulant. On examination he was alert and mentally normal. Except that he could perceive bright light in a small area of the left upper quadrant he was completely blind. There was no motor defect and no sensory loss. An E.E.G. at this time showed runs of medium voltage abnormally fast waves (22 a second) in both frontal lobes, and

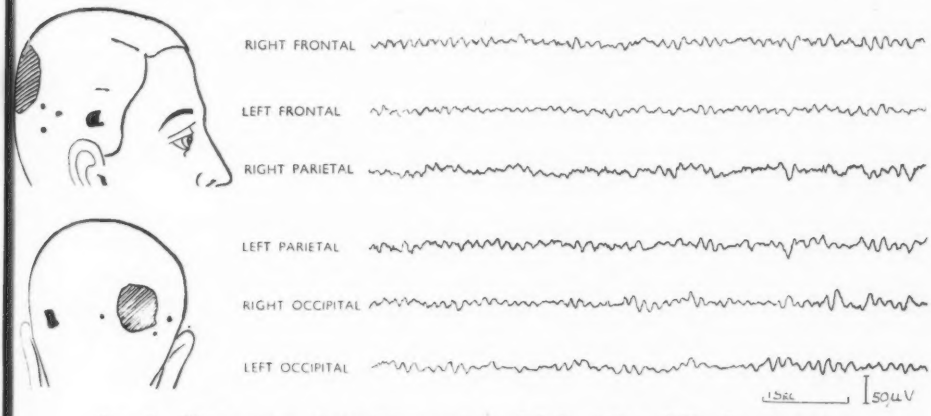

FIG. 8.—The position of the injury and the E.E.G. of Case 9090. Post-operative occipital bone defect is shaded and the position of the metallic foreign bodies is indicated in black. Electroencephalograms show a fairly high voltage dominant frequency of 10 a second propagated into the frontal lobe. It is very slightly suppressed in the left occipital region.

of 7 cycle sine waves in the right parietal region. These were thought to have arisen indirectly as a result of the injury. There was also relative suppression of the dominant frequency in the posterior temporal region on the left. Records elsewhere showed a fairly high voltage stable dominant frequency of 10 cycles propagated into the frontal lobe (fig. 8). It was not inhibited by bright light or opening the eyes.

Case 9219.—In contrast to the previous case this is an example of almost complete blindness of cerebral origin, which was associated with complete absence of all physiological frequencies. The patient, an infantryman aged 22, was hit by shrapnel on March 30, 1945. The missile entered the left mid-parietal region and passed inwards, backwards and downwards through the left hemisphere and across the middle line to lodge against the bone on the posterior end of the

Sylvian fissure on the right. He therefore had a severe parietal and parieto-occipital injury on the left with a large track cutting right through the posterior part of the right hemisphere (fig. 9). The day after wounding he was in semi-coma and had signs of a bilateral pyramidal lesion. At operation a bone defect 2 × 1 cm. was found in the middle and posterior parts of the left parietal bone. "necrosed brain was sucked out, leaving a cavity which tapered downwards,

FIG. 9.—The position of the bone defect and foreign bodies in Case 9219. A mid-parietal bone defect with indriven bone was the centre of four radiating linear fractures. The large metallic foreign body was in the opposite occipital lobe.

inwards and backwards with a further extension downwards. The main track was seen to approach the mid-line at about 6 cm. from the brain surface. It was not followed." He remained in semi-coma for a week and at the end of this time he was blind except for preservation of sensation to bright light in the outer part of the left field. Pupils were dilated, equal and reacted briskly. There

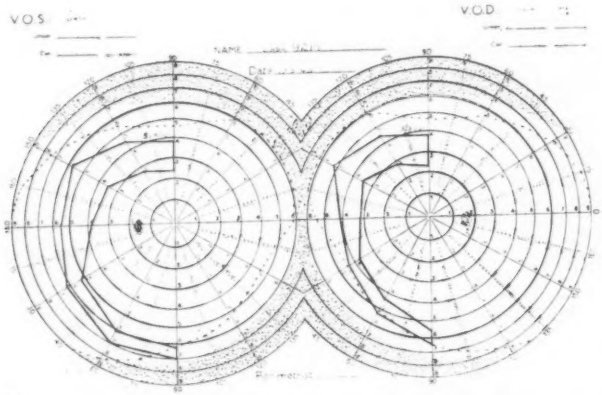

FIG. 10.—The visual fields of Case 9219 showing the small crescentric area of sparing.

was now a mild right hemiplegia with impairment of joint sense and light touch on both sides, most marked on the right and a mild dysphasia. The conditions of motor and sensory functions and of speech improved and nine weeks after wounding the patient was ambulant with a mild right hemiplegia, with sensory loss, and some dysphasia. The visual fields then showed sparing of vision in a

crescent at the periphery of the left field (fig. 10). The E.E.G. recorded four weeks after injury showed bilateral abnormality. "No evidence of any physiological dominant frequency was seen. There were persistent high voltage 1 and 2 a second waves arising in the left parieto-occipital region. Waves of a similar kind were seen on the right side, but their voltage was lower. Farther forward runs of 4 a second sine waves occurred with short runs of faster activity. The total suppression of the dominant frequency is probably due to the bilateral parieto-occipital injury." It is possible but unlikely that the patient has no physiological dominant frequencies before injury.

Comment.—In Case 9090 a bilateral homonymous hemianopia, cortical blindness, due to destruction of the area striata on one side and the optic radiation on the other was associated with almost complete sparing of the normal "alpha" frequencies. In Case 9219 with almost complete blindness due to bilateral damage of the optic radiation in a biparietal penetrating wound there was bilateral complete absence of these frequencies. The difference between the cases rested not in the damage to visual pathways but in the site of the cerebral lesions. Whether the "alpha" wave is suppressed depends upon whether the cortex which gives rise to it is damaged and not upon damage to the visual pathways.

The following conclusions upon the mechanism of suppression of normal and abnormal waves were drawn from the evidence obtained from study of penetrating brain wounds.

(1) Abnormal suppression of normal rhythms will result from complete destruction of cortex and from traumatic interruption of cortical function due to local concussion. The first state is irreversible, the second reversible.

(2) The degree of local suppression of the "alpha" rhythm depends partly on the severity and extent of the injury, and partly on the proximity to the focus of origin of the "alpha" rhythm: its position is closely related to the site of injury but it also depends on its proximity to the point of origin of the suppressed waves, the area involved depends almost entirely upon the proximity of the injury to the focus of origin of the "alpha" rhythm.

(3) Destruction of the focus of origin causes complete suppression of the "alpha" rhythm. In adults no other area of cortex seems to take on this activity.

(4) Interruption of physiological continuity of the cortex causes interruption of propagation of the normal "alpha" rhythm. This supports the view that spread of the potential changes is by neurones and not by simple electrical conduction.

(5) Focal suppression of normal frequencies results from local direct concussion of cortex—as in penetrating injuries, depressed fractures or tangential gunshot wounds. This phenomenon can occur without the

appearance of the large slow waves characteristic of brain dysfunction due to trauma, but slow waves seem to make their appearance when the percussion has caused structural as well as functional damage. Removal of the damaged brain will abolish these slow waves.

(6) The abnormal suppression of cortical electrical activity as a result of trauma is a phenomenon distinct from the production of abnormally slow waves, although they often co-exist.

(7) Suppression of abnormal waves in contrast to that of normal waves occurs only at the site of complete destruction, displacement, or inactivity of the damaged brain.

(8) When suppression of normal frequencies is associated with visual field defects it is not caused by interruption of visual pathways but by damage to the cortex which gives rise to these frequencies. The two phenomena are independent.

(9) All the factors described must be considered in interpreting the features of the "silent area" for clinical purposes.

Closed head injuries.

Symmetrical and generalized suppression.—When abnormal waves are seen in closed head injuries, suppression of normal frequencies is the rule. This suppression persists after the slow waves have subsided, and it may then be considered as the last sign of disordered function before full recovery takes place. When it occurs alone it may be a sign of minimal cerebral concussion.

The relationship of this suppression to the occurrence of slow waves, and to clinical recovery, has already been described in some detail (Williams, 1941*a*). In normals the amplitude of the physiological frequencies varies so much that in an individual subject the recognition of generalized abnormal suppression is difficult (Jasper, Kershman and Elvidge, 1940), but in a patient who is recovering from a closed head injury and who shows a persistent normal rhythm with an unusually low voltage, the voltage may be expected to increase with recovery. As the subject of generalized suppression of normal frequencies occurring after concussion has been dealt with by workers already quoted, it need not be pursued at the moment.

Asymmetrical and focal suppression.—Although generalized suppression of normal frequencies is commonly seen during concussion and recovery from it, a focal area of suppression is uncommon in closed head injuries in the absence of a complication such as a massive intra- or extra-cerebral hæmorrhage. Only 31 cases of focal suppression were found in the E.E.G.s in many hundreds of cases of closed head injury recorded at all intervals

from hours to years after the injury. "Silent areas" were so uncommon in closed head injuries that the cases in which they occurred were specially examined for causal factors. The following points emerged: 27 (87 per cent.) of the 31 patients had physical signs of focal brain damage—usually evidences of pyramidal damage or a defect in the visual fields—at the time of examination. Two of the other 4 had evidence of severe frontal contusion and the other 2 had a very severe closed head injury with signs of widespread cerebral damage, so that focal disorders may well have been masked by the general disturbance. The 31 cases with a "silent area" could also be divided in the following way:—

		Cases
(1)	Depressed fracture with local brain damage	14
(2)	Gunshot wound of scalp or bone without penetration	5
(3)	Closed injury with severe focal damage	5
(4)	Slight injury with mild and transient focal contusion	4
(5)	Closed injury with focal complication	3
		31

It is clear therefore that although 4 of the patients had no physical signs of focal brain damage, in every closed head injury with a "silent area" focal damage had occurred.

(1) *Depressed fractures.*—There is no fundamental difference as far as this study is concerned between focal damage caused by a depressed fracture with tearing of the dura, and a penetrating head injury. These 31 patients with depressed fractures may be divided into two groups, depending on the severity of the injury.

(*a*) *With extensive brain destruction.*—The E.E.G. in these cases showed much abnormal slow activity of the kind already described elsewhere. This was found especially in the neighbourhood of the injury, with suppression of all frequencies—both normal and abnormal—at the site of maximal damage. After operation for toilet of damaged brain the abnormal slow waves either diminished or disappeared, but the "silent area" always persisted. The E.E.G. in these cases is the same as if there had been dural penetration.

(*b*) *With small discrete contusion.*—In these cases there was a "silent area" with little or no abnormally slow activity. If abnormal waves were present in the area of damage they subsided before the "silent area" disappeared. This usually resolved completely. These cases are similar to others without a depressed fracture but with a focal contusion, of which Case 4166 is an example.

(2) *Gunshot wounds of scalp without penetration of bone.*—The effects

of lesions of this sort upon the brain seem to be similar to those caused by depressed fractures. All 5 patients had well localized disturbance of brain function, the result of local concussion caused by passage of a high velocity missile through the overlying tissues. In common with the previous patients they all had an area of brain with slight damage disturbing function rather than structure, which had the probability of complete recovery. Case 8029 illustrates this group.

Case 8029.—A gunner, aged 23, was shot in France by a rifle bullet in September, 1944. He remembered the whole episode. Examined at the Military Hospital (Head Injuries) later on the day of wounding, he was rational and well orientated, his memory was good but he was a little drowsy. He had a tangential wound of the right occipital and temporal regions, a bullet having entered an inch above the ear, penetrated soft tissues, grooved a gutter in the petrous temporal bone and emerged 3 in. farther back on the outer surface of the occiput. The only abnormal physical sign was a doubtful left lower quadrantic homonymous visual field defect. Motor and sensory functions were normal except that the left plantar response was not so active as the right. The scalp wound was cleaned up and closed. X-ray showed a tiny groove, ¼ in. long, in the right posterior parietal region, deep to the scalp wound. Recovery was rapid, the patient was up next day and visual fields were absolutely full when plotted five days after wounding.

An E.E.G. ten days after injury showed focal abnormality in the right posterior parietal region underlying the grooved bone. This consisted of well localized low voltage 2 to 7 a second waves with focal suppression of the normal dominant frequency of 11 a second over a wide area. A week later the focal suppression and the slow waves were still present.

Comment.—This is an example of a tangential gunshot wound with injury to the bone which caused concussion of the underlying brain with transient and minimal evidences of disturbance of function. The E.E.G. showed slow waves and a "silent area" which persisted after full clinical recovery.

(3) *Closed injury with signs of severe focal damage.*—In this group of 5 patients, although there is no depressed fracture or dural penetration, there is severe local damage to brain, and in the E.E.G. slow waves are invariably present throughout the hemisphere and are maximal around the area of suppression. The whole process of disturbance in the E.E.G. —slow activity, generalized suppression and focal suppression—may resolve completely, as in Case 584.

Case 584.—A driver, aged 21, was knocked down by a car in March, 1941, and had an exceptionally severe closed head injury and other superficial injuries including a laceration over the right parietal region. He was admitted the same day in coma. All limbs moved spontaneously, but all were spastic and both plantar responses were extensor. The pupils were small, equal, central and reacted to light. Blood-pressure was 180/70, pulse irregular, rate 80. Lumbar puncture showed a pressure of 135 with a blood-stained fluid. X-ray showed that

there was a long linear fracture crossing the right middle cerebral artery, but bilateral burr holes failed to show any extradural or subdural clot. He remained in coma, which gradually lightened, but was not fully alert for seventeen days. Post-traumatic amnesia was over four weeks, retrograde amnesia a week. During this time the patient lay rigidly in bed with no spontaneous speech. His face lacked expression, there was no visible emotional response and there was limitation of spontaneous movements. Visual fields were full. He was dysphasic and had a spastic hemiplegia with gross ataxia on the right. Sensation also seemed to be impaired on that side. Two months after injury he still had dysphasia although it was improving and the motor signs of hemiplegia were still present on the right side. There was more spontaneous speech and movement and facial expression was beginning to appear. There was evidence of serious

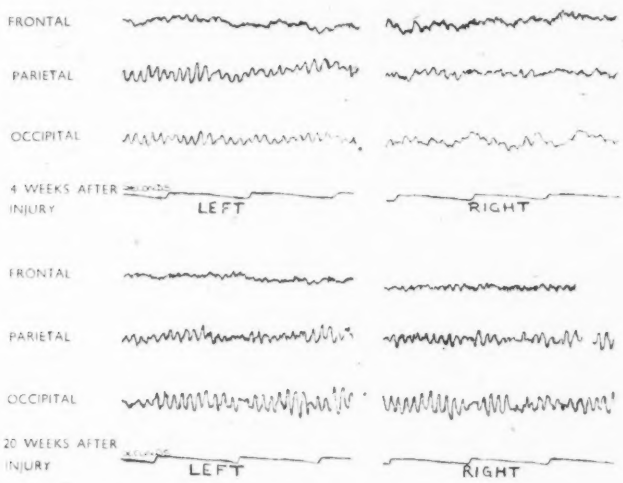

FIG. 11—Records obtained four weeks and twenty weeks after injury in Case 584. Records from comparable positions in both hemispheres show that suppression of the dominant frequency of 10 a second and abnormal 1 and 2 a second waves which were present in the right hemisphere four weeks after injury subsided completely before the twentieth week.

intellectual defect. Recovery was slow, and he was discharged from hospital in September, 1941—six months after injury. At this time there were serious defects in all forms of intellectual behaviour; there was residual dysphasia, affecting all forms of speech, and there was a mild right hemiplegia affecting the arm most severely. He was invalided, and follow-up showed that three years after injury there was still intellectual defect, slight disturbance of speech and a mild right hemiplegia. He was, however, in full employment. Air encephalography before discharge from hospital showed symmetrical and apparently normal ventricles. E.E.G.s were regularly repeated during his six months in hospital. At first, four weeks after injury, there was practically complete absence of the dominant frequency on the left side, although it could easily be recorded from the right (fig. 11). Abnormally slow waves (1 to 2 a second) were recorded from the right

side and from the frontal and occipital regions on the left, but these were absent in the "silent area." The comment was made that "the record is almost identical with some we have had recently which have resulted from a collection of blood between the cortex and the electrode." The slow waves gradually subsided and sixteen weeks after injury they could just be seen in the left posterior parietal region. At this time there was still slight suppression of the dominant frequency on that side. Twenty weeks after injury records were symmetrical and were thought to be normal (fig. 11).

Comment.—In this case a very severe closed head injury was associated with focal damage—presumably contusion and laceration—of the left parietal lobe. There was generalized disturbance in the E.E.G. with a "silent area" in the left parietal region. As clinical recovery advanced the slow waves subsided and the "silent area" resolved. The E.E.G. returned to normal while hemiplegic signs were still present.

(4) *Mild and transient focal contusion.*—Patients with closed head injuries with clinical signs of slight focal contusion to the brain may loose the evidences in the E.E.G. records of the focal abnormality early in the period of recovery, before the generalized abnormality has subsided. At this stage abnormal slow waves are widespread throughout the hemisphere and the dominant frequency will not have returned. Sometimes, as in these four cases, the functional disturbances caused by the contusion persist so that when the generalized slow waves have subsided, and the normal frequencies have elsewhere returned a "silent area" persists in the neighbourhood of the contusion. This area of inactivity finally disappears. An example of this sequence is provided by Case 4166.

Case 4166.—A 20 year old officer had a motor cycle collision on March 11, 1943. He had a closed head injury and was admitted to hospital unconscious. While unconscious he had three generalized epileptic fits. He had bruising of the right temple, bleeding from the right ear, and neck rigidity. Lumbar puncture gave bloody fluid with a pressure of 260 mm. water. There were subsequently no abnormal signs in the central nervous system except for deafness on the right. Post-traumatic amnesia was about four days. X-ray showed a linear fracture running from the posterior part of the right parietal bone into the petrous temporal. He made a steady recovery without any complications and went to a convalescent home six weeks after the injury and returned to duty with a full medical category three months after the injury.

An E.E.G. ten days after injury was abnormal. It showed medium voltage 2 to 4 a second waves throughout the hemispheres. These were most evident in the posterior part of the right hemisphere, and there was suppression of the dominant frequency in the right temporal region.

E.E.G. records repeated three months after injury when the patient was fully recovered showed marked improvement. The abnormal slow waves in the posterior part of the right parietal region had subsided. There was still very slight suppression of the dominant frequency in this area, but records from all other positions were quite normal.

Comment.—In this case a fairly severe closed head injury was associated

with a blow to the right side with a fracture over the right posterior parietal and temporal regions. E.E.G.s showed focal slow waves and suppression of the dominant frequency in the position of the blow and the fracture. Clinical recovery was uneventful, and the abnormalities in the E.E.G. subsided.

This brief survey makes it clear that focal suppression of "alpha" waves in closed head injuries only occurs when there is focal damage to brain, and that the mechanisms are the same as in penetrating wounds of the brain.

(5) *Closed head injury with focal complication.*—One patient with an unexpected "silent area" without signs of a local contusion was found to have an angioma at the area of suppression, another had a subdural clot on the affected side, and the third had a very severe head injury with a persistent protein content of 120 mgm. per c.c. in the cerebrospinal fluid. The nature of the lesion in the third case was not discovered. "Silent areas" in association with tumours, angiomas and hæmatomas will be discussed later, so that the present cases need not be described.

One common feature differentiates these cases of closed head injury with a "silent area" in the E.E.G. from the general run of closed head injuries—they all had an area of focal brain damage. Excluding the cases with extra-cerebral complications, this damage seems to have been of three types:—

(1) Complete destruction of the large area of cortex.

(2) Local high velocity percussion with little or no loss of brain tissue.

(3) Transient and minimal disturbance of function with full recovery.

Having analysed the factors causing suppression in cerebral trauma, the results will be applied to the findings in other abnormal states.

Subdural and Extradural Hæmatomas.

Twenty-one cases of intracranial hæmatoma were examined, 12 subdural—1 of these a hygroma—and 9 extradural. The time after the onset of symptoms at which the E.E.G. was recorded varied from three days to six months, and in most of the cases serial records were taken during the period of recovery. In all cases the diagnosis was proved at operation, and 12 had records before and after operation. The other 9 also had records after drainage of the hæmatoma. The 12 patients investigated before operation showed abnormal slow waves in the E.E.G. These were usually generalized, with maximal disturbance on the side of the hæmatoma. Six of the 12 also showed suppression of activity over the site of the hæmatoma. In the other 6 cases there was no doubt about the

absence of a "silent area," since the possibility of a subdural hæmatoma had been raised and a search for suppression of normal and abnormal waves had been made. In the 6 cases with a "silent area" the suppression was situated over the hæmatoma, and in all of them abnormally slow waves were recorded around the area of suppression. As there seemed from these results to be an equal chance whether or not a "silent area" would be found in association with a subdural hæmatoma, several factors which might determine this were studied with the following results:—

(i) *High intracranial pressure* was present in 5 cases—2 of which showed suppression.

(ii) *Period after injury.*—In the 6 cases with suppression this was 2 days, 10 days, 2 weeks, 4 weeks, 6 weeks and 6 weeks: in the 6 without it was 3 days, 2 weeks, 2 weeks, 3 weeks, 4 weeks, 6 months.

(iii) *Extradural v. subdural.*—Of the 6 cases with suppression, 2 had extradural and 3 subdural hæmatomas, and 1 had a subdural hygroma.

(iv) *Site of hæmatoma.*—5 out of 6 of the anteriorly placed hæmatomas showed no suppression whereas 5 out of 6 posterior hæmatomas had a "silent area" (for this difference $X^2 = 1{\cdot}4$, $P = 0{\cdot}20$). Case 6464 is an example of a posteriorly placed hæmatoma with suppression and Case 7812 of a frontal hæmatoma without.

Case 6464.—An aircraftsman, aged 24, hit his head in a rugger match on October 12, 1943. He was hazy about the rest of the game and had slight generalized headaches for the next fortnight. These gradually became worse, and he reported sick. Examination as a hospital out-patient, including X-ray, showed no abnormality. The headache persisted and was sometimes associated with nausea. In mid-January, 1944, he had transient periods of blurred vision. There were no fits or faints and there had been no disturbance of limb function. On examination there was doubtful blurring of the left optic disc, but no other abnormality was found. Admitted to the Military Hospital (Head Injuries) in February, again no abnormality was found on examination of the central nervous system, except for blurring of the left optic disc with some small linear hæmorrhages. X-ray of the skull showed calcification of the choroid plexuses, which were in the normal positions. Lumbar puncture showed a normal fluid under a pressure of 205 mm. While under observation in hospital he improved and operation was deferred, but later headaches returned, and on April 1 bilateral exploratory posterior parietal burr holes were made and a large chronic subdural hæmatoma was found. 150 c.c. of thick blood-stained fluid were removed from it. An exploring catheter was passed forwards from the posterior parietal burr holes for 5 cm. in the cavity of the hæmatoma. The wound was closed and subsequent recovery was uneventful.

An E.E.G. recorded immediately after admission in February showed diminution of the "alpha" rhythms on the left side. The suppression of activity was most marked in the mid-Sylvian region, but all the hemisphere behind the mid-Sylvian point was severely affected. No abnormally slow activity could be seen. Records from the right hemisphere were normal and showed an 11-cycle rhythm of normal distribution.

Records repeated at intervals after this showed no material change until operation.

Records made seven days after operation were quite normal. There was a medium voltage dominant frequency of 11 a second, symmetrically distributed in the hemispheres. No evidence of the "silent area" persisted.

Comment.—In this case a large chronic subdural hæmatoma was present. It extended over the left parietal lobe, centring in the posterior parietal region. It was associated with high intracranial pressure but had not caused clinical signs of focal brain damage. The E.E.G. showed marked suppression of normal frequencies over a wide area on the affected side without any slow waves. This suppression resolved completely after operation.

Case 7812.—A private, aged 29, had a trivial closed head injury in a parachute landing in April, 1943. This was followed by bilateral headaches which subsided in a few weeks. Four months later these headaches returned and he began to vomit. He then had suboccipital pain, became drowsy and was admitted to hospital on January 30, 1944. When examined he was drowsy, and had a stiff neck. The right pupil was slightly larger than the left, there was bilateral papillœdema, the left arm and leg were clumsy, reflexes were increased, and the plantar response extensor. There was no sensory change. Next day a lumbar puncture showed a pressure of over 300 mm. and the cerebrospinal fluid was straw-coloured at operation. A subdural hæmatoma was found on the right side and 180 c.c. of fluid were removed from it. The hæmatoma could be entered from burr holes over the frontal bone as well as over the parietal eminence. Exploration with a catheter showed that the hæmatoma covered the frontal, anterior parietal and temporal regions. Recovery was uneventful.

E.E.G.s recorded before operation showed generalized severe abnormality. This consisted of high voltage 2 to 6 cycle waves. There was no evidence of greater abnormality on one side, and there was no unilateral suppression of normal or abnormal waves. Records made after operation (three weeks) showed a low voltage dominant frequency of 10 a second which had been seen previously, but all the abnormal waves had subsided. Again there was no asymmetry in the dominant frequency.

Comment.—An anterior parietal subdural hæmatoma did not cause suppression of the dominant frequency, in contrast to a posterior parietal hæmatoma (Case 6464).

From this evidence it is apparent that the only factor which is directly related to the occurrence of suppression of frequencies with extra-cerebral hæmatomas is the position of the hæmatoma. As was the case with penetrating head injuries, the likelihood of suppression of normal frequencies depends on the proximity to the parieto-occipital area, the usual site of propagation of the dominant physiological frequencies. This will explain the absence of a "silent area" over the site of some hæmatomas, but it does not explain the mechanism responsible for its presence in other cases. The following observations are pertinent. First, suppression of

activity may be recorded whether both recording electrodes are over the middle of the hæmatoma—bipolar recording—or whether one is over its centre and another in an unaffected area, such as the pinna-monopolar recording. If the suppression were spurious, the result of high conductivity of the hæmatoma interposed between brain and electrodes, as has been suggested by Jasper and Kershman (1940), suppression should appear with two electrodes placed over the lesion, and be absent with a single electrode over the centre of the lesion. Direct examination of hæmatoma fluid shows that its resistance is of the same order as that of C.S.F. or brain or blood, and observation at operation has shown that suppression may occur with an acute and thin film of subarachnoid blood as well as with a thick-walled chronic hæmatoma. Secondly, return of electrical activity is rapid after removal of the hæmatoma, but the suppression may persist with gradual recovery for at least a day afterwards. This would not be so if the high conductivity of the hæmatoma were the only cause. Thirdly, when another lesion is associated with a hæmatoma, the abnormally slow waves which result are not suppressed. One case (679) was that of a head injury followed by a large subdural hæmatoma in the left anterior temporal and frontal regions. Very high voltage generalized slow waves were present, maximal over the area where the hæmatoma was later found. An intercerebral abscess was later localized after the hæmatoma had been removed. The slow waves which arose from the neighbourhood of the abscess persisted unchanged after aspiration of the hæmatoma. As abnormal slow waves may persist and normal frequencies be suppressed when the lesion involves the posterior parietal region, the mechanism of suppression with a hæmatoma appears to be the same as that produced by direct cerebral trauma which has already been described. Simple interference with recording of cortical electrical activity by the hæmatoma can therefore be excluded as the sole cause of suppression.

Other Conditions Causing True Suppression of Frequencies.

So far, in these results, the effects of direct brain injury have been used to elucidate the mechanism underlying the suppression of normal and abnormal brain potentials in abnormal states, and these observations have been applied to the results obtained in a group of patients with interruption of visual pathways and to the investigation of subdural hæmatomas. Focal or general suppression of the same sort may occasionally result from other lesions of the brain, but the mode of production appears to be the same as in the conditions already described. These miscellaneous conditions may consequently be considered quite briefly.

Masses replacing brain. Tumours.—As is so well known, the characteristic changes in the E.E.G. recorded from the neighbourhood of cerebral tumours consist of abnormally slow waves. Suppression of normal frequencies is usually associated with this abnormality, but sometimes this suppression may occur independently. Furthermore, a "silent area" may be seen in the middle of a zone of abnormal activity. Large *meningiomas* are more likely than other tumours to cause suppression. In these the "silent area" usually overlies the tumour but when the meningioma lies over the convexity in the parietal region, widespread suppression of normal frequencies may be seen. A "silent area" will be seen in the middle of a zone of abnormality if the tumour has a diameter great enough to limit undistorted electrical spread from the edge of the suppressed area to electrodes placed over its centre. This will partly depend upon the voltage of the abnormal waves.

When the tumour is associated with generalized abnormality, perhaps the result of high intracranial pressure, it may be impossible from the E.E.G. alone to decide whether an area of depressed activity represents an abnormal "silent area," or a relatively normal zone where abnormal activity is in fact decreased, without inter-relating the E.E.G. results with the clinical findings.

When a meningioma grows very slowly it may give rise to no demonstrable slow activity, but it may so replace or damage brain tissue that suppression of normal frequencies is seen. This suppression may be generalized throughout the hemisphere if the tumour involves the posterior parietal regions. An example of this is given in Case 4143.

Case 4143.—A senior N.C.O., aged 42, began to have focal attacks beginning in the left little and ring fingers in October, 1939. The attacks consisted of a "horrible twisting pain spreading to the shoulder with a sensation as though the arm were withering up." This was followed by involuntary movement of the arm, then unconsciousness and a tonic-clonic fit. The attacks recurred at irregular intervals, and the character of their sensory aura changed. A year after the onset he noticed a painless lump in the right parietal region which gradually got bigger and he began to have headaches. On examination the parietal boss was 2 in. from the mid-line and 6¾ in. from the glabella. Its diameter was 1½ in. There was very slight increase in tendon-jerks on the left, and the plantar response was not so good as the other side. At operation a meningioma weighing 35 grm. was removed. Its surface measurements were 6 by 4 cm.

A pre-operative E.E.G. showed high voltage 10 a second waves, with a normal distribution on the left side. Its voltage was lower on the right. Very careful examination around the exostoses failed to show any abnormal slow waves. Records seven days post-operative showed no change.

Comment.—A large, very slowly-growing meningioma in the parieto-occipital region caused suppression of the normal frequencies, without it giving rise to any abnormal waves.

Gliomas and other tumours are unlikely to give rise to a "silent area" unless a large intracranial cyst is present, and in only two cases was such a "silent area" encountered. One (Case 4732) had a large parieto-occipital astrocytoma with cystic degeneration, causing a complete homonymous hemianopia, with high intracranial pressure. The E.E.G. showed abnormality in the posterior part of the left hemisphere. In the posterior Sylvian region there were low voltage 2 to 4 a second waves. There was absence of the dominant frequency of 10 a second over a wide area, considerably greater than that showing the abnormal waves. The comment was made that "the character of the E.E.G. suggests that if the patient has a tumour it is not causing rapid destruction of cerebral tissue."

This then is an example of suppression of the *normal* dominant frequency by a lesion invading the parieto-occipital cortex. The cause of the large area of suppression was the site and not the size of the tumour. The other patient (Case 1000) had a very large solid infiltrating glioma of the right frontal lobe causing high intracranial pressure and diplopia without any localizing signs. The tumour was so large that both ventricles were occluded, and it was considered impracticable to open the dura. The E.E.G. showed severe abnormality in both frontal lobes, more evident on the left. The report read: "This localized disturbance is evidence against a posterior fossa tumour, but as the alternative diagnosis is a right frontal tumour it must be borne in mind that a relative absence of disturbance on the right side might be due to complete destruction of cerebral tissue." Such was found to be the case. This then is an example of focal suppression of *abnormal* waves, giving E.E.G. changes which could not be interpreted apart from the other clinical evidence. Suppression of normal frequencies (Case 4732) or of abnormal activity (Case 1000) may well be overlooked in cases in which the site and nature of the lesion is unknown because of the difficulty in interpreting this kind of record in such cases. Because of this, similar cases may have been overlooked, but even so the condition seems to be uncommon with infiltrating tumours. These two cases are the only ones recognized in over 200 cases of cerebral tumour examined.

Angiomas.—These lesions cause suppression of normal frequencies in the same way as tumours, but as they are so often found in the parietal and parieto-occipital regions, suppression of normal waves is relatively common, and as they usually do not cause rapid and progressive damage to brain tissue the suppression of normal frequencies is accompanied by little or no abnormally slow activity. Interpretation of the E.E.G. changes may be facilitated by other localizing signs, especially those seen by radio-

graphy. Occasionally there are no other signs caused by the lesion, and then an unsuspected angioma may become apparent after the discovery of an area of suppression. This occurred in Case 8430.

Case 8430.—A sergeant airgunner, aged 21, was kicked by a horse and suffered a closed head injury with an amnesia of three days. He made an uninterrupted recovery and was admitted to hospital three days after the injury without any abnormal physical signs. Routine electroencephalography showed normal records on the right side, but there was suppression of the normal frequencies on the left in the mid-parietal region, just above the line of the Sylvian fissure. X-rays showed a hair crack running into the left frontal sinus, but it also showed intracranial calcification at a depth corresponding to that of the cerebral cortex in the left mid-parietal region, just above the position of the Sylvian fissure. This calcification was characteristic of an angioma. The lesion was unsuspected and was unassociated with symptoms or signs. The absence of slow waves indicated that it was not actively damaging cerebral tissue.

Cerebral cysts.—An example of porencephaly associated with suppression of normal frequencies and with surrounding slow waves has already been published (Martin and Williams, 1938) and Case 4732, already quoted, was an example of a cystic tumour causing similar changes. Any form of cyst, if sufficiently large, will result in a similar zone of suppressed activity due to displacement of brain tissue. In Case 7839 obliterative ventriculitis had followed a penetrating wound of the right temporo-parietal region. This resulted in cystic dilatation of the temporal horn, with high intracranial pressure. Electroencephalography showed severe abnormality in the neighbourhood of the injury, a less marked disturbance elsewhere, presumably the result of the high pressure, and a zone of complete suppression of all activity over the right temporal lobe. Serial records were taken over many weeks, during which several operations were performed to aspirate the cyst and cauterize the choroid plexus in the cyst. The abnormal waves steadily decreased in number, voltage and period, but the "silent area" remained, even after complete aspiration of the cyst. Its persistence was probably due to the large amount of brain destroyed in the neighbourhood of the cyst.

Abscesses.—It is characteristic of acute abscesses that they produce very severe changes in the E.E.G.s recorded from their neighbourhood. In 50 cases of abscess studied, only one was found to have given rise to a "silent area." This patient (Case 8811) had a large chronic abscess in the left middle temporal area from which 90 c.c. and later 70 c.c. of pus were aspirated. Four months previously an extra-dural abscess had been removed from the left temporal fossa. Abnormally slow waves were present in all leads in the E.E.G., but their voltage was much lower over the site of the abscess than elsewhere. There was associated general suppression

of the normal frequencies. Two months after initial aspiration the abscess was removed. The E.E.G. still showed suppression of normal frequencies in the affected hemisphere with a focus of slow waves in the mid-temporal area. It is probable that in this case the "silent area" was caused by the extradural abscess (see section on hæmatomas) but there had also been displacement and destruction of brain tissue by the thick-walled abscess.

Vascular disorders and cortical atrophy.—Vascular occlusion with associated ischæmia of cerebral tissue may be associated with suppression of electrical activity in the affected area. This was so in Case 8397 where there had been a cerebral air embolism. Rubin (1940) and Strauss *et al.* (1943) have described suppression of "alpha" activity in cases of cortical atrophy.

Case 8397.—A sapper, aged 28, had a gunshot wound in his chest in November, 1944, which caused a hæmo-pneumothorax with surgical emphysema around the wounds of entry and exit. He was very ill and was cyanosed. When found later the same day he was confused and was variously noisy and drowsy. No paresis of limbs was found. Next day he had a left hemiplegia. Two days after injury he was rational, orientated and alert. He had a complete left homonymous hemianopia and spastic hemiplegia with impairment of sensation to light touch, joint movement and vibration. No evidence of carotid damage was found and Horner's syndrome was absent. X-ray of the skull showed no abnormality. The C.S.F. pressure was 100 mm. and the fluid normal in all respects. His general and neurological condition steadily improved, and a month after wounding he had very slight signs of pyramidal damage on the left, no sensory defect, a left homonymous lower quadrantic field defect and slight intellectual defect. He went to a convalescent home and on return, three months after wounding, he was anxious to return to duty. In view of the field defect he was invalided. A diagnosis of air embolism of the right middle cerebral artery was made.

An E.E.G. recorded five weeks after the embolus, when very considerable clinical recovery had taken place, showed that "the dominant frequency of 10 a second was suppressed throughout the right hemisphere and was virtually absent in the temporal regions. There were also low voltage 1 and 2 cycle waves which were not present on the left. Records from the left side and from the right frontal lobe were quite normal. The appearances were those of a "silent area" involving most of the right hemisphere, particularly the parietal lobe. In my opinion, the changes represent the later stages of recovery from cerebral insult involving the right mid-parietal region."

Comment.—In this case there was temporary cessation of function in the right hemisphere, probably the result of air emboli causing complete hemianopia, hemiplegia and hemianæsthesia. Very considerable recovery of function took place, and five weeks afterwards, when sensory recovery was complete, and motor almost complete, the E.E.G. showed suppression of normal frequencies throughout the affected hemisphere, with little slow activity. This probably represented the final stages of the return of the E.E.G. to normal.

In three cases in which the internal carotid artery had been successfully tied on one side for obliteration of damaged and aneurysmal vessels, without any interference with the function of that hemisphere, no evidence of suppression of electrical activity or of any other abnormality could be found after careful comparison of the two hemispheres.

Unexplained suppression.—Rarely, in an epileptic or psychotic subject, or in a patient with other kinds of behaviour disorders, records may show persistent and abnormal asymmetry of the dominant frequency. This may or may not be associated with dysrhythmia, and it may occur in the absence of abnormal signs or of evidence of cerebral atrophy. Case 7927 is an example of such a condition.

Case 7927.—An officer, aged 21, was admitted to hospital for investigation of abnormal, irresponsible and anti-social behaviour. His past life had been uneventful and there had been no suspicion before the present disorder of any aberration in behaviour. His performance in studies and at games had been average and he had always been reliable and well liked. He had had two years successful service as a member of aircrew before the illness began, and had had no serious illnesses. His parents had been stable and one sister was also quite normal. There was no history of fits, neuroses or psychoses in any near relative. In May, 1944, he felt unduly sleepy for a week and on one occasion went to sleep on duty. In June a change was noticed in his behaviour which was described by his wife and other relatives, and by officers on his station. He became erratic, unreliable and irresponsible in the air, so that his crew lost confidence in him. On the ground he became irritable and moody, at home extravagant and uninhibited, on the station he drank heavily, lied freely, absented himself without leave, committed foolish but profitable frauds for which he gave the most plausible excuses, and when arrested became negativistic, truculent and aggressive. In July, 1944, he had a focal head injury caused by exploding ammunition. He had a swelling and an abrasion of the left temple, an absolute post-traumatic amnesia of three hours and a partial amnesia for two days, but he returned to duty after a week. After this he had attacks of giddiness, in some of which he fell down and in one of which he was seen to be pale, limp and apparently unconscious for fifteen minutes. He also complained of mild headaches and of recurrent attacks of depression. The abnormal anti-social behaviour continued for four months, until admission to hospital. On examination he was shallow and facile and was found to be completely untrustworthy. He was evasive and furtive in conversation. His intelligence was only average and his educational attainment low for an officer. His memory was normal on testing. No abnormal physical signs were found, the C.S.F. was normal in all respects and no cells were present. The Wassermann reaction was negative in blood and fluid. X-rays of skull and an air encephalogram were quite normal. Many opinions were given that his abnormal behaviour was probably the result of an organic disorder, that it had not been present before June, 1944, and that it preceded the head injury. He was invalided and referred to a civilian hospital for observation, undiagnosed, with the possibility of a frontal tumour in mind. An electroencephalogram recorded on two separate occasions showed relative diminution of the dominant frequency in the right temporal region. Elsewhere there was a fairly high voltage stable dominant frequency of 11 a second of normal distribution. There were

no abnormally slow waves in the neighbourhood of the focal suppression and no activity of an epileptic kind was seen. When records were repeated afterwards the "silent area" had subsided and the E.E.G. was normal.

Comment.—This is a case of a man with an unexplained personality disorder probably of an organic origin who showed a "silent area" in the right mid-temporal region, presumably the result of cerebral dysfunction, for which no cause has yet been found.

Spurious Suppression of Frequencies.

All the conditions so far described cause disappearance of normal and abnormal frequencies by actual suppression of cerebral electrical activity as recorded in the E.E.G. Alterations in the physical properties of the structures between the electrodes and the brain may affect the voltage of the recorded waves. Such changes may be produced by increase or decrease in local resistance or by increase in the distance between brain and recording electrodes. Abnormal conditions causing spurious asymmetry of waves—normal and abnormal—or giving rise to "silent areas" can be divided according to whether they increase or decrease the brain-electrode resistance.

Decreased Resistance.

Bone defect.—Here the lowered tissue resistance due to absence of bone and the decreased brain-electrode distance causes local increase in voltage of waves. This is often associated with abnormally slow waves caused by damage to underlying brain, and the record is sometimes disturbed and marred by rhythmic artefacts caused by tissue movement at the edges of the defect as a result of cardio-respiratory alterations in intracranial pressure. In penetrating head injuries true suppression of activity under the bone defect may consequently be masked by the facility with which waves of lower voltage can be recorded in the region of the defect. Were this not so the proportion of patients with penetrating head injuries who show "silent areas" would be even greater than 30 per cent. (page 128).

Metallic obturators (tantalum).—Tantalum, used to repair traumatic defects in the skull, is a stable element which causes little or no tissue reaction. Little surface oxidation or other chemical action takes place at body temperature so that the measured resistance of a sheet is negligible, even after prolonged exposure to a solution of salts (Venable and Stuck, 1943; Pudenz, 1943). Records have been taken in 12 patients with tantalum plates *in situ*, in 10 of whom comparison was made between records obtained before and after insertion of the plate. In all cases records made from paired electrodes placed over the plate showed marked diminu-

tion in the normal or abnormal waves, as the case may have been—a "silent area." Records made with a single electrode over the plate and one at a distance, e.g. on the ear or elsewhere on the scalp, showed no difference from similar records obtained from a symmetrical point on the other hemisphere (fig. 12). The explanation of the "silent area" which is seen with "bipolar" electrode placements across a tantalum plate appears to be that the potential differences have short-circuited through the highly conducting plate. When one electrode is placed over such a plate, the

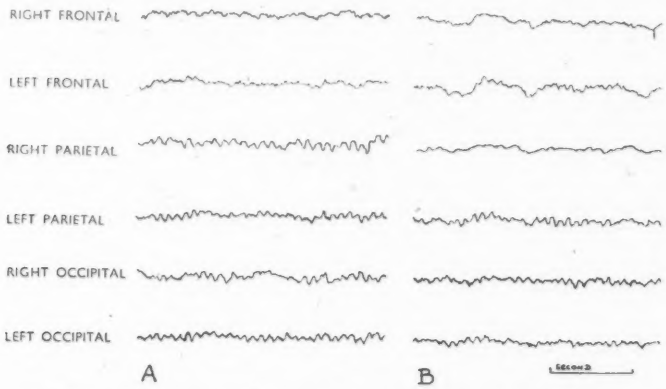

FIG. 12.—Records from Case 8001. There was a large bone defect in the right mid-parietal region. (*a*) Records obtained seven months after a penetrating head injury before insertion of a tantalum plate. (*b*) Records with identical amplification and electrode placement two weeks after the insertion of a tantalum plate into the bone defect. There has been complete suppression of the dominant frequency of 10 a second recorded from the right parietal region. Two electrodes situated over the plate were used for this record. The dominant frequency recorded from the occipital regions is symmetrical. The record from the right occipital region was made with one electrode over the plate and one over the intact scalp.

plate really behaves as an extension of the electrode, so that the opposite effect might be expected, that is a wave of higher voltage. In practice this is not seen, presumably because of the relatively high conductivity of normal tissue in the comparable area on the opposite side. As "silent areas" seen with tantalum plates are due to physical changes which are unrelated to the site of origin of the waves, they will be found whatever the position of the plate, so long as there is electrical activity to be recorded from that position. It is now the general practice to perforate the tantalum sheets in many places. In these circumstances there is tissue

continuity through the holes, resistance may be the same as in other areas, and the tantalum exert no evident effect.

Increased Resistance.

Acrylic (plastic) obturators.—Records have been compared before and after insertion of an acrylic plate into a skull defect in 6 cases. In 3 of these cases there was a demonstable suppression of electrical activity recorded over the graft, either with "bipolar" or "monopolar" electrodes. This is in contrast to the changes with tantalum plates where "bipolar" leads show apparent suppression and "monopolar" show no change. All 3 patients in whom suppression could not be seen had anterior frontal bone defects, and in each the frontal records from the corresponding position on the other hemisphere has consisted of virtually straight lines. It is likely that the cases did not differ in other respects from those in which a "silent area" was observed. In the cases with acrylic plates the spurious inactivity under the plate is of course due to the high resistance insulating the brain from the overlying electrodes.

Discussion.

All the results which have been presented in this paper are concerned with persistent and abnormal suppression of cerebral electrical activity. This suppression has throughout been considered as distinct from the rapidly reversible suppression of the "alpha" waves which is produced by attention, however this is initiated and maintained (Adrian, 1944). The dominant physiological rhythm usually originates in Areas 18 or 19, association areas primarily concerned with vision, but Adrian has pointed out that this rhythm is most readily inhibited by visual attention because attention is so readily aroused by visual stimulation in man. Walter (1938) noted that auditory stimuli, too small to inhibit the rhythm in normals, would inhibit it in a blind man, the explanation being that it had aroused attention in him much more readily. It is therefore attention and not vision as such which inhibits the rhythm.

Case (1940 and 1942) found inhibition of the "alpha" rhythm on the contralateral side in 8 patients with a homonymous hemianopia, the result of lesions in the cerebral hemispheres. As the optic radiation had been damaged in all the cases he concluded that as "an interruption in the optic radiation produced a homonymous hemianopia and at the same time apparently stopped the occipital 'alpha' wave from the involved hemisphere. . . . 'Alpha' waves may be cyclic electric phenomena circulating in a chain of neurones, one link of which is the optic radiation." The

results of the present study of the effect on the E.E.G. of perforating gunshot wounds of the brain show clearly that suppression of the "alpha" wave occurs when the cortex from which it is propagated is destroyed or disturbed, and that the association of a hemianopic field defect is the result of anatomical relationship rather than of physiological interdependence, for the radiations or the area striata can be damaged and cause a hemianopia without suppression of the "alpha" activity. It should be observed that most of Case's patients had infiltrating tumours, which may have invaded more widely than the signs suggested. We were fortunate in having available so many cases with uncomplicated and discrete wounds of the brain. The results from this material do not support Case's views. It seems probable, rather, that as Adrian has suggested, this rhythm is independent of visual function as such, and that it is an epiphenomenon depending on the vital activity of cells in or near Areas 18 or 19. Cells in other areas generate different rhythms with different properties from those of the "alpha" waves. The flicker rhythm which can be recorded from one hemisphere on flickering stimulation of the contralateral visual half field is an example of such a rhythm artificially induced, and the frontal and parietal "alpha" rhythms (Case, 1942) are others.

Abnormal inhibition of the "alpha" rhythm is, then, independent of visual function. It is most readily seen when a large area of cortex is displaced or destroyed, but it also occurs when cortex is percussed, as it is under a depressed fracture, or in the vicinity of the track of a high velocity missile. As this inhibition of activity can be produced in the adjacent cortex by a tangential bullet wound of the scalp, it presumably occurs also in the brain surrounding the track of a penetrating gunshot wound. If this were so it would explain the absence of abnormally slow waves and the presence of a "silent area" after operation for toilet of the intracerebral track of a missile. Here most of the disorganized brain which was producing slow waves is removed, and as the activity of the brain in the immediate neighbourhood of the track is suppressed, the result is a "silent area." A comparable "silent area" can be produced in cats by local percussion of brain around the recording electrode (Williams and Denny-Brown, 1941). These authors concluded that "concussion is associated with diminution or cessation of the electrical activity of the whole hemisphere, as recorded in the E.E.G." This suppression, whether focal or general, is directly related to the degree of abnormally slow activity present (Williams, 1941), but the results of the present work seem to show that it can occur as an entirely independent phenomenon. The application of this phenomenon to clinical problems has been described, and the difficulties

of its interpretation are apparent in the results. Successful interpretation must depend on careful integration of the E.E.G. findings with those of other methods of examination. When the mechanisms which govern inhibition of the normal rhythms in wounds of the brain are applied to inhibition in other disorders, the results are consistent and understandable. The degree and extent of suppression of the "alpha" rhythm depends on the site of the damaged cortex in relation to the area of propagation of that rhythm and not on the size, depth or direction of the wound. Thus, subdural hæmatomas overlying the posterior half of the hemisphere cause suppression, but those in the anterior half cause no such change. It is interesting that Sjaardema and Glaser (1942) who described the changes in the E.E.G. in 3 cases of subdural hæmatoma, found slow waves with no "silent area," and that all the cases had anterior hæmatomas. At least one of the two cases described by Jasper, Kershman and Elvidge (1940) in which "silent areas" were found had a posterior parietal hæmatoma.

Applying the results of the study of cerebral wounds to the clinical conditions described in this paper has made it clear that although "silent areas" in the E.E.G. are relatively uncommon apart from trauma, their interpretation is difficult and calls for careful study in each case.

Kornmüller (1944) in a review which has become available since this paper was completed, has described asymmetry of the "alpha" rhythms in abnormal states. He was particularly interested in differences in the persistence and continuity of this rhythm, rather than in its amplitude, but he also commented upon the importance of persistent suppression of the "alpha" rhythm. He found that although gaps in the continuity of the rhythm were often associated with cerebral lesions, persistent suppression of "alpha" waves of the sort described in the report were uncommon. Although his observations were upon a rather different aspect of the subject, his results are complementary to those presented by us.

Summary and Conclusions.

When abnormally slow rhythms appear in the E.E.G. as a result of cerebral damage, whatever the cause, the normal rhythms are suppressed: the degree of damage, abnormal electrical activity and suppression are usually directly related to each other. This abnormal suppression is quite distinct from the rapidly reversible suppression of the normal "alpha" rhythm which is induced by attention.

In some circumstances normal or abnormal rhythms may be suppressed without slow activity, alone or together, and this suppression may be

localized. The phenomenon has been investigated in man, and the factors determining it have been studied.

A large number of abnormal subjects with diverse lesions, and an adequate number of normal controls were used. The suppression resulting from focal damage or destruction of brain tissue, caused by penetrating gunshot wounds, was studied and the results were applied to the interpretation of similar suppression associated with other cerebral lesions.

The following conclusions were reached:—

(1) Focal suppression of the "alpha" rhythm is always abnormal, as it was not seen in a large group of normals.

(2) Suppression occurs around penetrating gunshot wounds of the brain, and also in the cortex underlying non-penetrating gunshot wounds, and depressed fractures, and also in other circumstances in which brain is violently percussed.

(3) It is caused by complete destruction of brain tissue, but it also results from temporary suspension of activity as a result of percussion. In the first case it is irreversible, in the second full resolution can occur.

(4) This focal suppression is indistinguishable from the generalized suppression of "alpha" activity which is associated with concussion of the brain.

(5) The suppression results directly from physiological or anatomical interference with the area of cortex initiating or propagating the "alpha" rhythm. Because of this the extent, position, and intensity of the suppression are mainly determined by the proximity of the lesion to that cortex, and they do not necessarily reflect the extent, position or severity of the causal lesion. Thus a small lesion of the parieto-occipital cortex will suppress all "alpha" activity in the affected hemisphere, whereas a frontal, temporal or occipital lesion may have no such effect.

(6) Suppression of the "alpha" rhythm is independent of interruption of visual pathways. There is consequently no support for the view that the optic radiations are a link in a neuronal circuit which sustains the rhythm.

(7) Interruption of physiological continuity of the cortex causes interruption of propagation of the "alpha" rhythm. This supports the view that spread of the potential changes is by neuronal and not simple electrical conduction.

(8) Focal or general suppression of the normal rhythms may occur independently of the appearance of abnormal slow activity.

(9) Suppression of abnormal slow waves, which are the direct effect of

cerebral damage, is markedly different from the suppression of normal rhythms. Its position, extent and severity are a direct reflection of the position, extent and severity of the injury. It is usually irreversible.

(10) A "silent area" caused by suppression of normal and/or abnormal waves is determined by these conditions whatever the nature, size or position of the cerebral lesion.

(11) A "silent area" is very common in penetrating head injuries, but uncommon in closed. It is only seen in a closed head injury when there has been severe focal percussion of brain; then the local condition mimics that of a penetrating injury. Removal of damaged brain may abolish abnormal activity and leave an area of suppression.

(12) A "silent area" is not characteristic of subdural or extradural hæmatomas. It is only found when the hæmatoma covers the posterior parts of the hemisphere, and short-circuiting through the overlying hæmatoma is not the main cause.

(13) Cerebral angiomas often cause "silent areas," probably because they commonly lie over the parietal lobe.

(14) "Silent areas" are not commonly associated with other cerebral lesions.

(15) Because factors other than the lesion determine the presence and character of a "silent area," application of the phenomenon to clinical diagnosis is difficult, and requires the integration of all other evidences of the lesion with those recorded in the E.E.G.

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SPINAL TRACTS SUBSERVING MICTURITION IN A CASE OF ERB'S SPINAL PARALYSIS.

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In 1892 Erb attempted to differentiate clinically a form of spinal disease occurring in individuals with a previous history of syphilis, the special features being predominating involvement of the bladder, some spastic paralysis and only slight sensory disturbance. No post-mortem material was available at that time, but subsequently cases coming to autopsy showed predominating lesions in the posterior parts of the lateral columns of the cord in the region of the direct cerebellar tracts but often extending forwards into the tract of Gowers and deeply into the pyramidal tracts. Occasionally the posterior columns were also slightly involved. The most detailed study of pathology is that of Foix, Crusem and Nacht (1926) who emphasize the above distribution of lesions in the cord and note its association with a chronic arachnoid meningitis on the posterior surface of the cord, extending from the inferior cervical to the mid-dorsal region below which the lesion decreases in severity. The meningeal and vascular lesions in this case conformed very closely with their description.

The syndrome is extremely rare, and it is of course not infrequently mixed with tabetic or other neurosyphilitic manifestations. The clinical symptoms in the case presented here were confined to the urinary tract: there was no subjective or objective change in ordinary superficial or deep sensation; there was no weakness or spasticity of the legs, the only evidence of pyramidal tract involvement being bilateral extensor plantar responses. In view of the highly selective nature of the lesion, it is thought that the case illustrates the site of spinal pathways concerned with voluntary control of micturition in man.

The essential clinical details are as follows:—

A woman, aged 47, came under observation on account of a urinary tract infection in July, 1941. It was noted that the bladder failed to empty properly and she then had a right-sided infected hydronephrosis. Eighteen months later the right kidney had ceased to function and the left, previously normal, had become hydronephrotic; after a transient uræmia (blood urea 175 mg. per cent.) due to exacerbation of infection, she made a partial recovery. Twenty-eight months after first observation she died in uræmia. Parallel with the progression of uræmia and infection she became anæmic, hæmoglobin falling from 96 per cent. in July 1941 to 52 per cent. just before death. Full investigation of this anæmia showed that it was not of macrocytic type.

Bladder symptoms.—Nocturnal "frequency" was the first symptom noted a few months before she was first seen. Nocturnal incontinence was obvious from the time of her first admission, and this symptom was persistent. The bladder contained 240 c.c. residual urine and the patient was never aware of any sensation of bladder fullness. Attempts at voluntary "emptying" of the bladder invariably left the organ palpable a handsbreadth above the pubis. The bladder was thus "automatic," functioning at intervals (incontinence), there was no voluntary control and bladder sensation was not perceived.

Objective manifestations in the central nervous system.—No abnormalities were found in the cranial nerves or upper limbs. The abdominal reflexes were present except the lower right.

No sensory loss could be detected in the legs. Motor power was good. Deep reflexes were equal and natural. Plantar responses were weakly extensor. Co-ordination was unaffected. The anal reflex was not recorded.

The cerebrospinal fluid was examined four times. Pressure was low (40 mm.) and Queckenstedt's test showed no abnormality. Protein was raised (50-75 mg.),

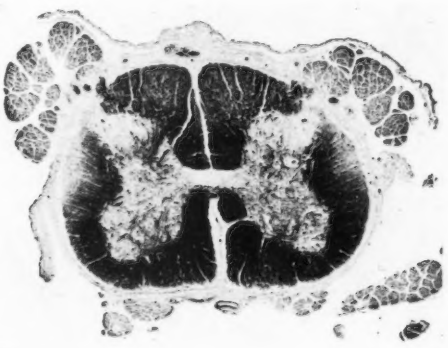

FIG. 1.—Weigert-Pal stained section of the spinal cord in the first lumbar segment. Pallor indicates symmetrical degeneration in the posterior marginal parts of the lateral columns.

globulin tests being positive. Cells did not exceed 6 per c.mm., Lange test was always completely negative but the Wassermann was positive. Blood Wassermann was negative at first, but later became "suspicious" when the Kahn test became positive.

Superficial veins were so small that intravenous anti-syphilitic therapy had to be suspended after a few injections of mapharside. Following a course of intramuscular acetylarsan the blood Wassermann and Kahn became negative, but no improvement occurred in the clinical state.

Post-mortem confirmed the presence of severe disorganization of both kidneys by infected hydronephroses. The bladder was distended with a necrotising hæmorrhagic inflammation of its wall. There was a terminal pneumonia.

The brain was normal. The spinal cord showed a milky white adherent thickened pia-arachnoid extending over the posterior surface of the cord beginning in the lower cervical, maximal in the mid-dorsal region and diminishing as

the lumbar segments were reached. The anterior surface of the cord appeared normal.

On microscopy the pia-arachnoid was thickened and the vessels showed round-celled cuffing and hyaline thickening as they passed into the cord tissue. Weigert-Pal sections showed a bilaterally symmetrical zone of degeneration immediately anterior to the posterior cornua lying superficially in the lateral columns. These degenerated fibres, most conspicuous as a bundle in the first lumbar segment, became less prominent in the dorsal region, where they seemed to be intermingled with healthy fibres, and in the cervical region they could no longer be identified (fig. 1).

Discussion.

The selective involvement of bladder function makes it probable that sensory afferents and motor efferent fibres subserving micturition pass in a tract of fibres lying in the posterior and superficial part of the lateral columns. This is the situation in which similar pathways were found in the cat by Barrington. This author believed that both ascending and descending degenerations were demonstrable following sections in this region, and that both afferent and efferent pathways were present. The fibres decussate in the segments of the cord from which the pelvic nerves arise. They seem to be recognizable as a distinct bundle in the lumbar region only. Higher up they are probably mingled with the fibres of the direct cerebellar tract. The findings in this case suggest that the micturition pathways in the spinal cord in man follow an anatomical path similar to that in the cat.

Summary.

In a case of Erb's syphilitic spinal paralysis with symptoms almost entirely confined to the bladder the spinal cord showed symmetrical degeneration in the posterior and superficial part of the lateral column, most marked in the lumbar region. Higher up the fibres were less distinct, probably being intermingled with the direct spino-cerebellar tract.

I am indebted to Professor J. H. Dible and Mr. F. J. F. Barrington for their help in the study of the sections.

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Notices of Recent Publications.

The Diagnosis of Nervous Diseases. By J. Purves Stewart. Ninth Edition. Arnold and Co., London. 1945. Pp. 880. Price 30s.

It is unnecessary to introduce a book that has been so familiar to, and so greatly valued by, medical readers for the past forty years. The appearance of its ninth edition indicates its continued popularity and usefulness. Its original plan remains unchanged, but additions have now made of it a volume of some 880 pages. There comes a time in the history of any successful medical textbook, when the advance of knowledge with the inevitable changes of outlook necessitate a recasting, and when the mere addition of new facts makes not for clarity but for incoherence. Despite the remarkable thoroughness with which the author of this distinguished book has sought to bring it fully up to date, the need for some recasting is very apparent. Thus in the paragraphs dealing with poliomyelitis, sciatica, Ménière's syndrome and other topics, we find the new side by side with the old which it has rendered obsolete. The bulk of the volume might be materially reduced were some of this old matter eliminated, and it may be doubted whether in a work primarily concerned with diagnosis, it is useful or necessary to list all the possible varieties of histologically differentiable intracranial tumour, and to describe their microscopic features. The wealth of clinical experience revealed in its pages would surely stand out more clearly and to greater advantage if a judicious pruning of the obsolete and the irrelevant were achieved, and the book would be smaller and less expensive.

What is Hypnosis. By Andrew Salter. Richard R. Smith, New York. Pp. 88. Price $2.

The author, who is more familiar with the literature of hypnosis than with that of physiological psychology, believes that in describing hypnosis as a "conditioning process", he elucidates its nature. Because training has so much to do with hypnotic behaviour, he has been led to make wide, uncritical and inapt use of Pavlov's concepts. He is, however, an experienced and ingenious hypnotist; his techniques are therefore informative, though they include methods of teaching people to hypnotize themselves into a "trance" whenever they think it desirable. He is naïve enough to believe, on the strength of his ability to induce anæsthesia to pain and auditory anæsthesia to gramophone records of an air raid, that one in every five or eight soldiers might be taught to make himself immune to whatever sounds and pains he wished; "it is not impossible to imagine battalions of self-anæsthetized soldiers going into battle" (p. 56).

Klinische und Erbbiologische Untersuchungen über die Heredoataxien. By Torsten Sjögren. Copenhagen. 1943. Pp. 197. Price 15 Dän. Kron.

This monograph includes some account of 188 cases of hereditary ataxia in Sweden, distributed in 118 families. The author classified his cases into 5 groups of which Friedreich's ataxia—his Group I—includes 84 cases in 44 families and Pierre Marie's ataxia—his Group III—includes 64 cases in 36 families; the remaining

40 cases falling into the rather rare and to some extent atypical forms of the disease which occur occasionally in all populations and may, or may not, approximate to one or other of the two main clinical types or be transitional to them.

Seventy-four individuals belonging to Group I and 26 members of Group III were examined by the author. Clinical details are described and analysed to show their variation and incidence in the different groups, their relationship to the duration of the disease and their resemblance in different members of the same family.

The genetic section of the work includes much detailed analysis and the author has made use of methods elaborated by Lenz, Bomstein, Weinberg and Haldane; he concludes that Friedreich's ataxia, with a very high degree of probability is due to a recessive gene and that Pierre Marie's ataxia is almost certainly due to a dominant gene. If Professor Sjögren has found groups of cases in Sweden homogeneous from the clinical standpoint and also from the genetic standpoint it is a discovery of considerable interest. An examination of published cases as a whole has not hitherto fallen into such clearly defined categories; cases indistinguishable clinically from Friedreich's ataxia have been reported which suggests manifestation in the heterozygote and a proportion of cases of spastic ataxia appear to result from a recessive gene.

The volume contains a great wealth of facts embodied in 25 tables; amongst other features it provides systematic information concerning the age of onset of the disease, its duration and the age at death of patients—such facts as are eagerly sought for by the geneticist as well as by clinicians who are interested in the vital statistics of the disease.

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